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Volume II

FINAL REPORT

STUDY OF AN ATTITUDE CONTROL SYSTEM FOR THE ASTRONAUT MANEUVERING UNIT

Contract NASw-841

15 July 1964

HONEYWELL | Aeronautical Division

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Prepared by:

W. E. Drissel
R. L. Haines
R. J. Kell
D. N. Lovinger
D. M. Moses

Approved by: J S Norton
J. S. Norton
Section Head
Space and Armament Systems
Space Section

for R. V. Aronson
L. D. Kuechenmeister
Program Administrator

Honeywell Inc.
Aeronautical Division
Minneapolis, Minnesota

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SPECIFICATIONS

This is the second of three volumes comprising the final report of work perforr d under NASA Contract NASw-841, "Study of Attitude Control System for Astronaut Maneuvering Unit". Volume I comprises the technical discussion of work performed, and Volume III consists of the instrumentation and circuit drawings developed under the contract.

SECTION I

REQUIREMENTS FOR THE ASTRONAUT MANEUVERING UNIT ATTITUDE CONTROL SYSTEM

SECTION I
REQUIREMENTS FOR THE ASTRONAUT MANEUVERING UNIT ATTITUDE CONTROL SYSTEM

1.0 SCOPE

1.1 Requirements

N65-14952

This specification defines requirements for an attitude control system (ACS) for an astronaut maneuvering unit (AMU). It also includes requirements for a controller to be used by the astronaut in commanding translational or rotational movement. Pertinent data for related subsystems is given.

1.2 Statement of the Problem

Future space missions will require astronauts to leave their spacecraft and travel to a target. Once there, they will perform some work task, inspection, assembly, etc. When their work is complete, they will return to their spacecraft.

For the foreseeable future, astronauts will perform this maneuver by orienting mass expellant jets and applying translational thrust. During an orbital transfer, translational thrust also will be required for error correction.

Proper orientation of translational jets and error sensors implies attitude control and hence moment-producing devices. So long as mass expellant jets are required for translational thrust, it seems most unlikely any other moment-producing devices will be attractive on a weight-size-power basis.

1.3 Constraints

1.3.1 In view of the expected translational thrust misalignments, it is most likely that an automatic attitude control system will be required.

1.3.2 The human eye (plus sighting devices) will probably be the only error sensor available for line-of-sight angle sensing during the rendezvous maneuver. Prior to and during translation, the astronaut must have as large a visual field as practicable, to permit searching for and locking on the target. During search, the scanning process should be facilitated by attitude control while during translation attitude stabilization will be necessary to prevent loss of visual contact with the target.

1.3.3 After arrival at the target, the astronaut must have attitude control capability in order to orient himself properly for performance of his tasks. After attitude orientation at the target the astronaut must be provided with mechanical body restraint to permit application of arm and hand forces on the tools being used. He should have maximum freedom of arm motion and finger flexibility to successfully manipulate tools as needed. No work tasks will require counteracting moments produced by the ACS, except in the movement of tools or material.

1.3.4 The ACS should at all times prevent angular rates from exceeding certain maximum values, in order to prevent loss of orientation and onset of confusion on the part of the worker. In the event high rates (or tumbling) occur, the astronaut should be equipped with a means for rapid recovery.

1.3.5 During translation, the limit cycle should not be annoying to the astronaut in respect to frequency and amplitude of cycling, or restrict his capability in solving the guidance problem.

1.3.6 Size, Weight, Power -- The ACS must be compatible with life support, communications, thrust propulsion system, available batteries, and imposed weight limitations.

2.0 APPLICABLE REFERENCES

2.1 NASA Contract NASw-841

2.2 Test Conditions -- Functional, electrical, and mechanical design must be compatible with the space environment and AMU mission and configuration.

3.0 ATTITUDE CONTROL SYSTEM DESIGN REQUIREMENTS

3.1 General

3.1.1 The function of the ACS will be to control attitudes and attitude rates of of an astronaut wearing a backpack AMU during rendezvous and performance of work tasks.

3.1.2 The ACS will be part of an AMU which will comprise, in addition, a life support system, a bio-electric structural interface, a translational propulsion system, a controller, power supplies, and a communications system.

3.1.3 The ACS shall consist of attitude sensing, valve driving and signal processing circuitry.

3.1.4 The ACS shall operate in three modes: synchronous, normal limit operate and extended limit operate -- and shall be compatible with an emergency mode.

3.1.4.1 Synchronous Mode -- The gyros are held at their nulls, and jet actuation is prevented so that no large rotations would be required if switched to either operate mode.

3.1.4.2 Normal Limit Operate Mode -- The ACS will stabilize the astronaut and maintain him in the desired attitude within the tolerances of Paragraph 3.2.1. Upon actuation of the controller, the ACS shall provide a means of rotating the astronaut in either direction about the x, y, or z axis. The astronaut should have a choice of three rates: high speed for gross adjustments, and two slower rates for fine attitude control. The astronaut shall also have the ability to command two levels of translational acceleration along both directions of his principal axes. For rotation, the controller will command rates such that when the command is removed, body motion will stop without counter-command. For translations, the controller shall command acceleration such that when the command is removed, so are the translational forces.

3.1.4.3 Extended Limit Operate Mode -- This is the same as normal limit operate mode, except that attitude tolerances are those of Paragraph 3.2.2 instead of 3.2.1.

3.1.4.4 Emergency Mode -- In event of an ACS malfunction resulting in loss of control or undesirable accelerations, the astronaut shall be provided with means of immediately disengaging the ACS, of stopping the inadvertent motions produced by the malfunction, and of engaging an emergency minimum-performance system to permit return to the base vehicle.

3.1.5 The system will be similar in function to the Mercury ASCS, Gemini ACME, and Apollo SES.

3.1.6 The ACS sensors and control electronics shall weigh less than 10 pounds and consume less than 360 watts maximum. Volume of the ACS sensors and control electronics shall be less than 250 inches^3.

3.1.7 Reliability goal for the ACS shall be 0.9980 for a four-hour mission. Reliability is defined as the probability the ACS fulfills the performance requirements listed in Paragraphs 3.1.4.1 and 3.1.4.2 and defined in Paragraph 3.2 without resort to emergency modes of operation.

3.2 Detail

An inertial coordinate system is established with the X-axis in an arbitrary direction, the Y-axis at right angles and the Z-axis to form a right-handed set. A set of right-handed principal axes (x, y, z) is established in the AMU -- the x-axis pointing in the direction of main translational thrust, y-axis "out the right wing", and the z-axis approximately head-to-toe. The inertial system (X, Y, Z) is rotated into the AMU (x, y, z) system by first a yaw angle (ψ) about the Z-axis, a pitch angle (θ) around an intermediate pitch axis, and a roll angle (ϕ) around the x-axis.

3.2.1 Attitude Control Requirement for Rendezvous

3.2.1.1 Command attitudes must be continuously variable through 360 degrees in either direction around the x, y, z axes.

3.2.1.2 In Normal Limit Operate, with no thrust applied, the ACS shall hold set point angles within the following limits (including limit cycle amplitude) for a period not to exceed 20 minutes:

Yaw	±1°
Pitch	±1°
Roll	±3°

3.2.1.3 In Normal Limit Operate, with ± x axis thrust applied and the center of mass within the limits given in Paragraph 5.3, the ACS shall hold the set point angles within the following limits (including limit cycle amplitude):

Yaw	±5°
Pitch	±5°
Roll	±7°

3.2.1.4 In Normal Limit Operate, with ± y or ± z axis thrust and the center of mass within the limits called out in Paragraph 5.3, the ACS shall hold the set point angles within (including limit cycle amplitude):

Yaw	±5°
Pitch	±5°
Roll	±7°

3.2.1.5 With the ACS in Normal Limit Operate, if a new attitude is commanded, the ACS shall command attitude rates within the following limits:

Yaw	< 40 deg/sec
Pitch	< 40 deg/sec
Roll	< 40 deg/sec

3.2.1.6 Angular acceleration shall not exceed 1.5 rad/sec^2 in roll and pitch and 0.75 rad/sec^2 in yaw.

3.2.2 Attitude Control Requirements for Work Tasks

3.2.2.1 Command attitudes must be continuously variable through 360 degrees in either direction around the x, y, and z axes.

3.2.2.2 In Extended Limit Operate, with no thrust applied, the ACS shall hold set point angles within the following limits (including limit cycle amplitude):

Yaw	±10°
Pitch	±10°
Roll	±10°

3.2.2.3 In Extended Limit Operate, with the ± x axis thrust applied and the center of mass within the limits given in Paragraph 5.3, the ACS shall hold the set point angles within the following limits (including limit cycle amplitude):

Yaw	±10°
Pitch	±10°
Roll	±10°

3.2.2.4 In Extended Limit Operate, with ± y or ± z axis thrust and the center of mass within the limits called out in Paragraph 5.1.1, the ACS shall hold the set point angles within:

Yaw	±10°
Pitch	±10°
Roll	±10°

3.2.2.5 With the ACS in Extended Limit Operate, if a new attitude is commanded, the ACS shall command attitude rates within the following limits:

Yaw	< 40 deg/sec
Pitch	< 40 deg/sec
Roll	< 40 deg/sec

3.2.2.6 Angular accelerations shall not exceed 1.5 rad/sec^2 in pitch and roll and 0.75 rad/sec^2 in yaw.

4.0 DESIGN REQUIREMENTS - CONTROLLER

4.1 General

4.1.1 The controller shall be designed to allow the astronaut to command translational or rotational movement, through control of the translational propulsion system.

4.1.2 The controller will be part of an AMU which will comprise, in addition, a life support system, a bio-electro-structural interface, a translational propulsion system, an attitude control system (as defined in Paragraph 3.0), power supplies, and a communication system.

4.1.3 The reliability goal for the controller shall be 0.9975 for a four-hour mission. Reliability is defined as the probability the controller will perform the function described in Paragraph 4.1.1 without resorting to emergency modes of operation.

4.2 Detail

4.2.1 The operator shall be provided with an emergency ACS release in the event of a malfunction. The release control shall be continuously accessible and simple to operate, requiring only one short movement to actuate it. The emergency control shall not be located where it can interfere with normal operational procedures, and shall not be liable to inadvertent actuation.

4.2.2 The controller shall be mechanized using voice actuation.

4.2.3 A basic single voice command sequence shall result in a controller output command duration of one second.

4.2.4 Sustained controller command output shall be obtained with a verbal "repeat command instruction".

4.2.5 Provision shall be included for correcting (or changing) a command at any time before the command has been executed.

4.2.6 A single word "stop" command shall be included that will remove all commands from the system. The translational system shall revert to Coast mode, and the ACS shall revert to attitude hold using the reference which existed at the time the "stop" command was given. No release function shall be necessary for the system to accept new commands after the "stop" command has been given.

4.2.7 An "ACS off" command shall be provided. System power shall remain on in this mode. Attitude gyros shall be in an attitude synchronous mode of operation. Reaction jet operation must be prevented. Normal operation should resume any time a normal command sequence is given. Attitude reference shall be that existing at the time of the command, provided that angular rates are less than 20 deg/sec.

4.2.8 Commands shall consist of the following:

4.2.8.1 Translational

4.2.8.1.1 Jet commands in the fore and aft direction, up or down, and to either side shall be mechanized.

4.2.8.1.2 Two thrust level commands shall be included.

4.2.8.1.3 Mechanization shall be such that a "Jet on" time in response to a single command sequence shall be obtained as follows:

Axis	Low Thrust Mode (sec)	High Thrust Mode (sec)
Fore and aft	0.075	1
Up and down	0.075	1
Side	0.075	1

4.2.8.1.4 For sustained commands, the low thrust controller output shall be at a 1-cps pulse rate. The high thrust controller output shall be constant for the duration of the sustained command.

4.2.8.2 Rotational

4.2.8.2.1 Jet commands in pitch, yaw, and roll and in each sense (plus and minus) shall be mechanized.

4.2.8.2.2 Three levels of attitude rate commands shall be included.

4.2.8.2.3 Mechanization shall be such that attitude rates shall be obtained as follows:

Axis	Precision Mode (deg/sec)	Low Rate Mode (deg/sec)	High Rate Mode (deg/sec)
Pitch	0.15	3	20
Yaw	0.15	3	20
Roll	0.15	3	20

4.2.8.2.4 A low (guidance rendezvous) and a high (work task) limit cycle amplitude mode switching capability upon command shall be included.

4.2.9 In the event of a malfunction in the ACS or propulsion systems necessitating disengagement of the ACS, the astronaut shall be provided with a means for recovering from inadvertent tumbling. Because the astronaut may have difficulty determining the direction and amount of his tumble, recovery shall be facilitated by effecting recovery in one plane at a time. Emergency controls, reasonably accessible and easy to operate, shall be specified for tumbling recovery, rotation, and translation with the ACS disengaged. The emergency controls may be located wherever practicable, and operated by any suitable means.

Since the emergency controls may be an integral part of the translational propulsion system, design responsibility shall be limited to specification only. Compatibility with the ACS and controller shall be of major concern. The ACS design shall include all appropriate emergency mode circuitry.

5.0 DESIGN DATA

The ACS and controller design shall be based on related subsystem characteristics defined as follows:

5.1 Human Factors

5.1.1 Arm movement limits are as defined in Figure I-1.

5.1.2 No head movement inside the helmet occurs.

5.1.3 Visual capability is as defined in Figure I-2.

5.2 Thrust Propulsion System Characteristics

5.2.1 The basic jet configuration is as given in Figure I-3.

5.2.2 Nominal thrust rating of each reaction jet shall be 15 pounds.

5.2.3 Reaction Jet Characteristics

5.2.3.1 Hydrogen Peroxide System

5.2.3.1.1 Valve dead time = 10 to 15 ms for turn-on and turn-off.

5.2.3.1.2 Thrust rise time expressed as a single lag time constant measured from initiation of valve movement:

T. R. = 20 ms for hot catalyst beds.
T. R. = 80-100 ms for cold catalyst beds.

5.2.3.1.3 Thrust decay time expressed as a single lag time constant measured from initiation of valve movement:

T. D. = 20 ms

5.2.3.1.4 Thrust amplitude shall be within 10 percent of nominal.

5.2.3.1.5 Valve current design level shall be 1.0 ampere. Input impedance design level shall be 30 mh and resistance 28 ohms. Valve pull-in shall occur at 0.5 ampere maximum and drop-out at 0.1 ampere minimum.

5.2.3.2 Bi-propellant System

5.2.3.2.1 Valve dead time = 5 ms for turn-on.

5.2.3.2.2 Valve dead time = 1 ms for turn-off.

5.2.3.2.3 Valve rise and decay time = 2 ms.

5.2.3.2.4 Thrust rise time expressed as a single lag time constant measured from initiation of valve movement:

T.R. = 0.0058 second

5.2.3.2.5 Thrust decay time expressed as a single lag time constant measured from initiation of valve movement:

T.D. = 0.0058 second

5.2.3.2.6 Minimum impulse obtainable is equal to rated thrust times 0.0173 second.

5.2.3.2.7 Thrust amplitude shall be within 10 percent of nominal.

5.2.3.2.8 Valve current design level shall be 1.0 ampere. Input impedance design level shall be 30 mh and resistance 28 ohms. Valve pull-in shall occur at 0.5 ampere maximum and drop-out at 0.1 ampere minimum.

5.3 AMU Configuration

Astronaut, suit, and AMU (backpack) configuration is as follows:

5.3.1 Mass

	Maximum (slugs)	Minimum (slugs)
Astronaut	5.09	5.09
Suit	0.65	0.65
AMU	5.90	3.70
Total	11.64	9.44

5.3.2 Astronaut Positions

Mass distribution, and mass center and joint locations for the astronaut plus suit for the positions upon which the study shall be based are given in Figure I-4.

5.3.3 AMU Location

The position of the mass center of the AMU relative to the astronaut is given in Figure I-5.

5.4 Long Tether Line Acceleration

The ACS design must be compatible with accelerations up to 8 fps^2 caused by a long tether line attached to the AMU. The line of action of the acceleration shall be considered to pass through the total center of mass for position 1 of Figure I-4 and Figure I-5, and parallel to the x-axis.

It is assumed that a harness attached to the AMU will be utilized to constrain tether line forces through the total center of mass location as a means of minimizing associated angular accelerations. Tether line forces shall be directed nominally "forward" in all instances.

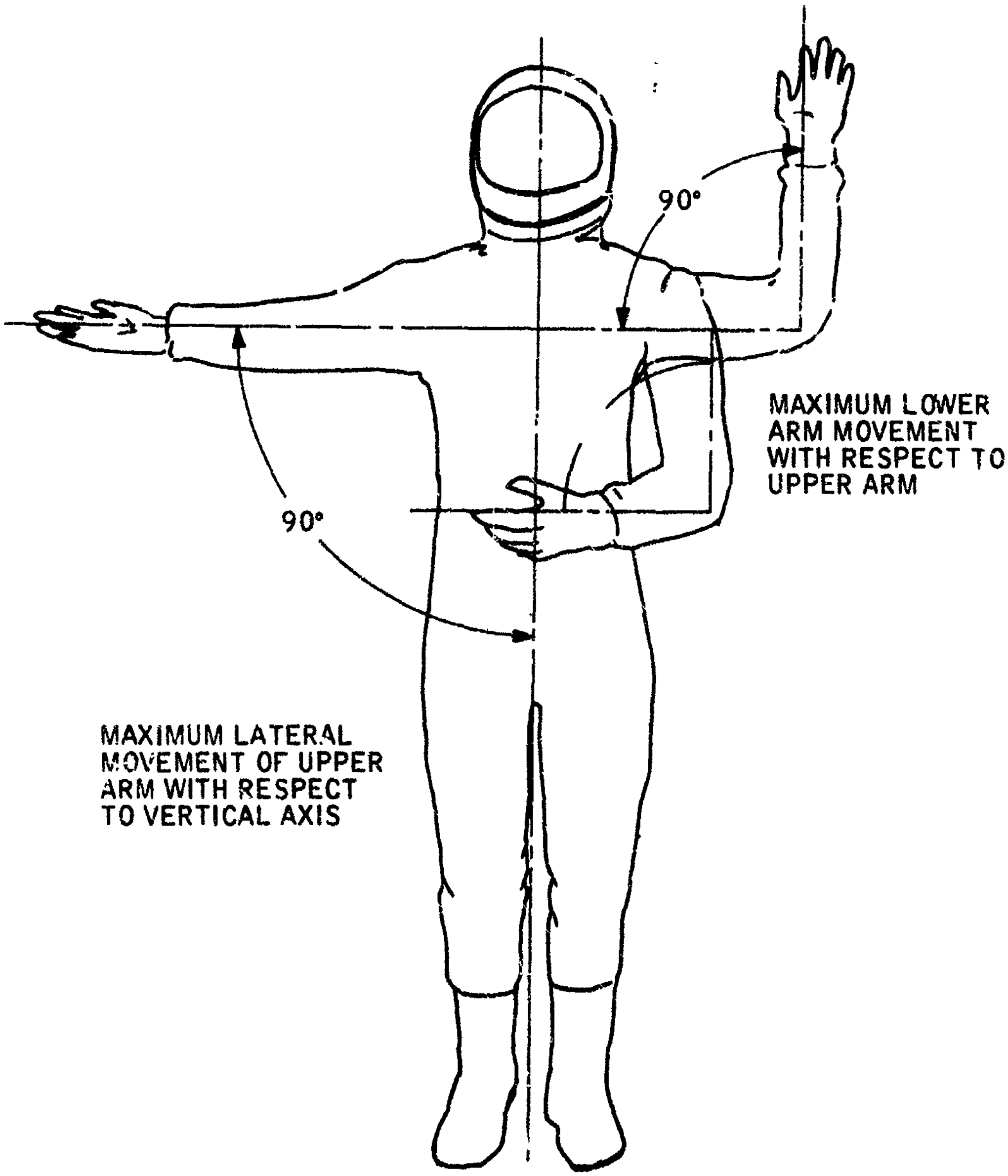


Figure I-1. Arm Movement Limits

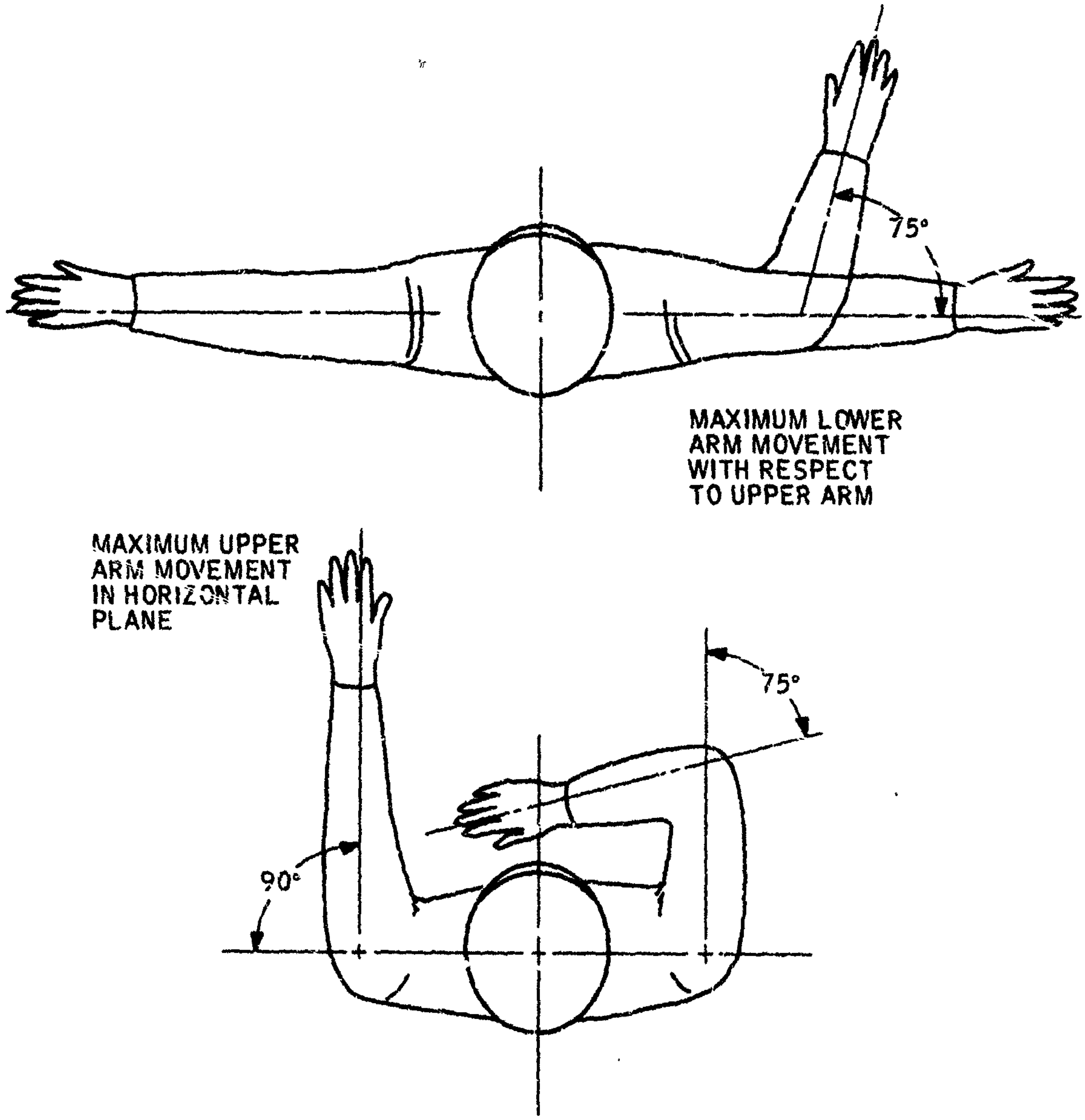
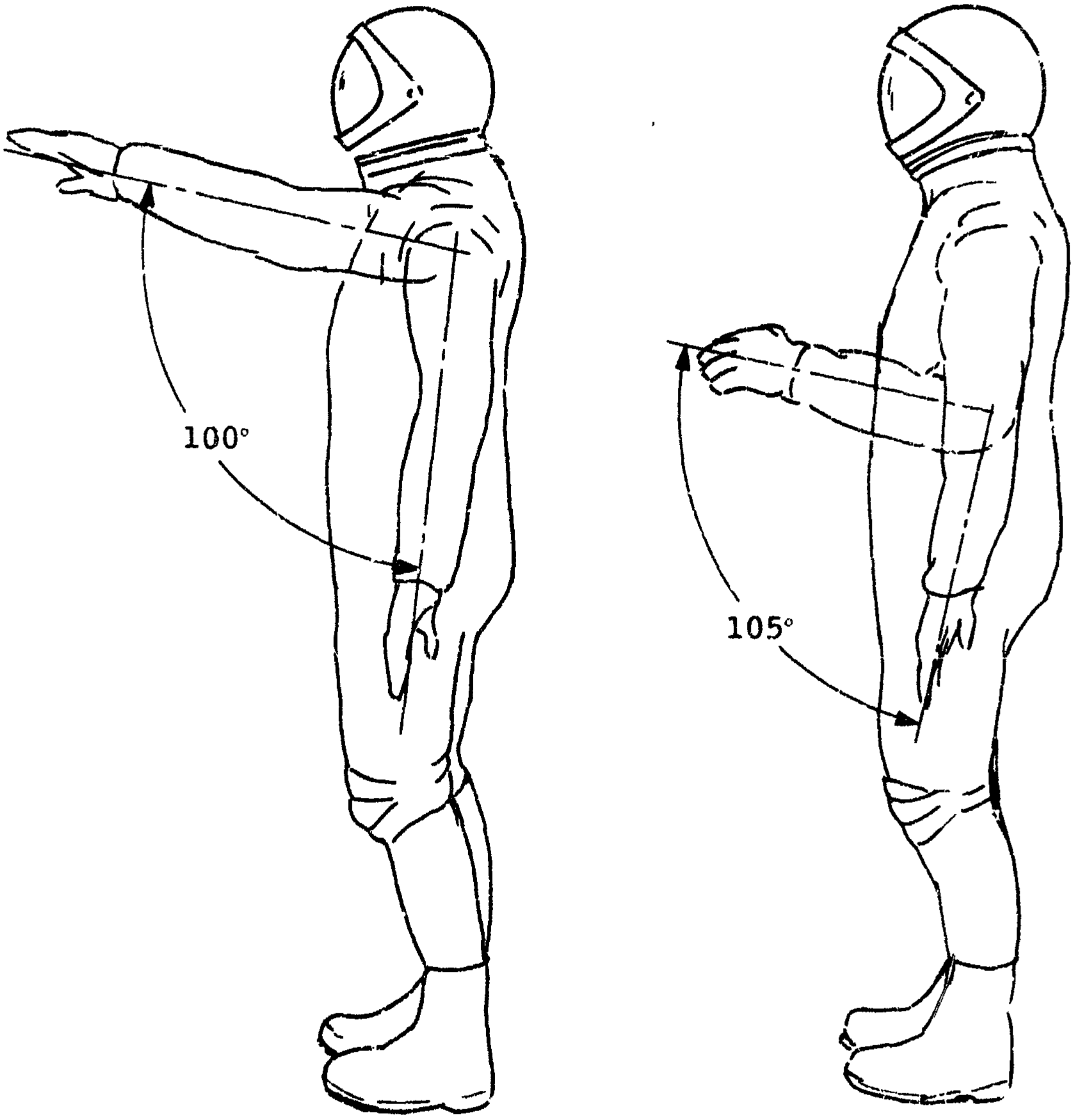


Figure I-1. Arm Movement Limits (Continued)



MAXIMUM FORE-AND-AFT MOVEMENT OF UPPER ARM WITH RESPECT TO VERTICAL AXIS

MAXIMUM LOWER ARM MOVEMENT WITH RESPECT TO UPPER ARM

Figure I-1. Arm Movement Limits (Continued)

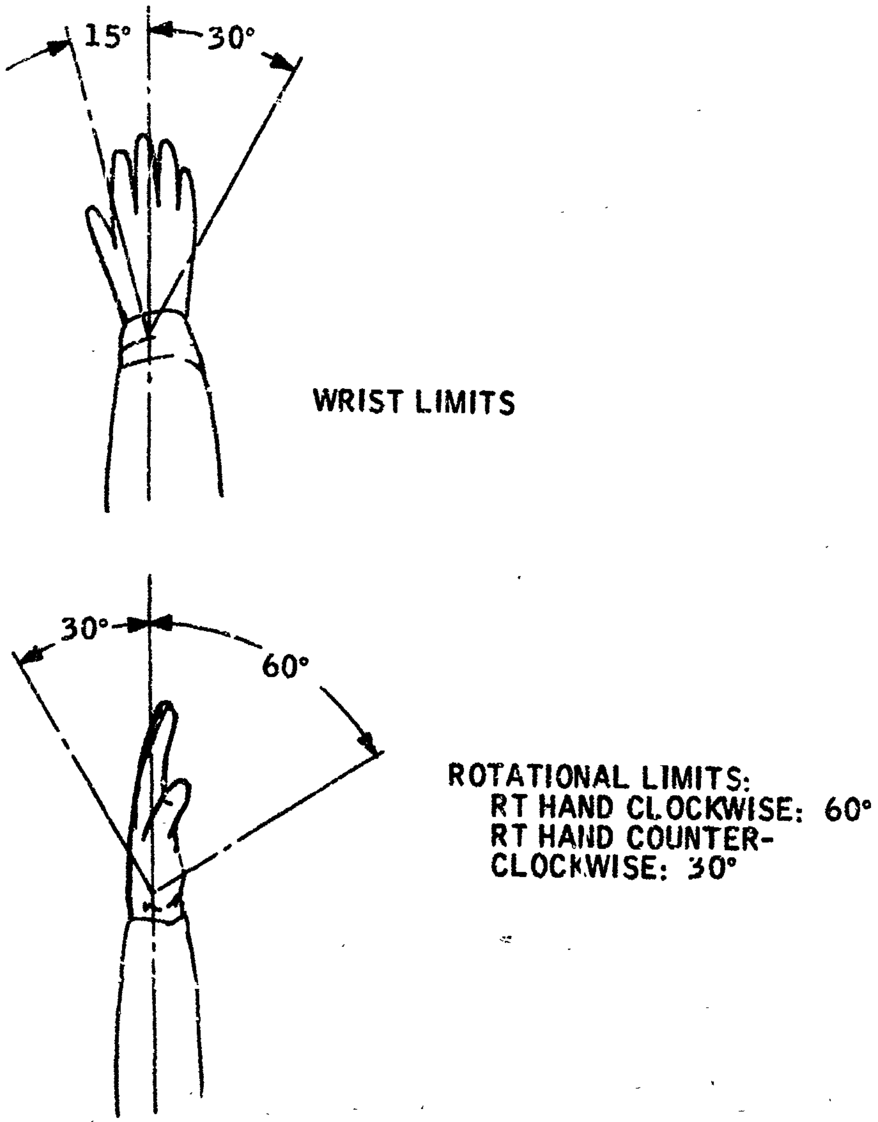


Figure I-1. Arm Movement Limits (Continued)

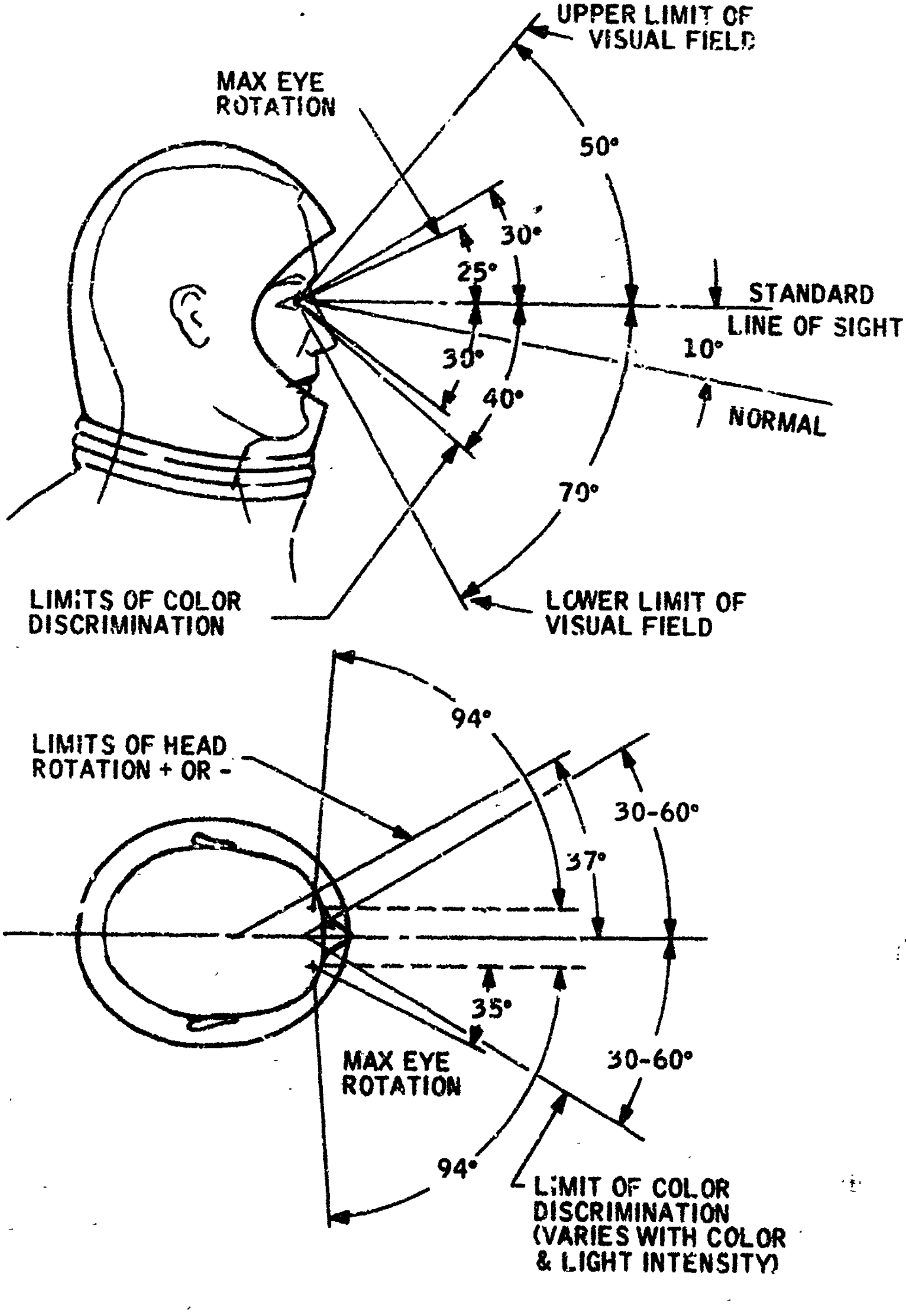


Figure 1-2. Visual Limits

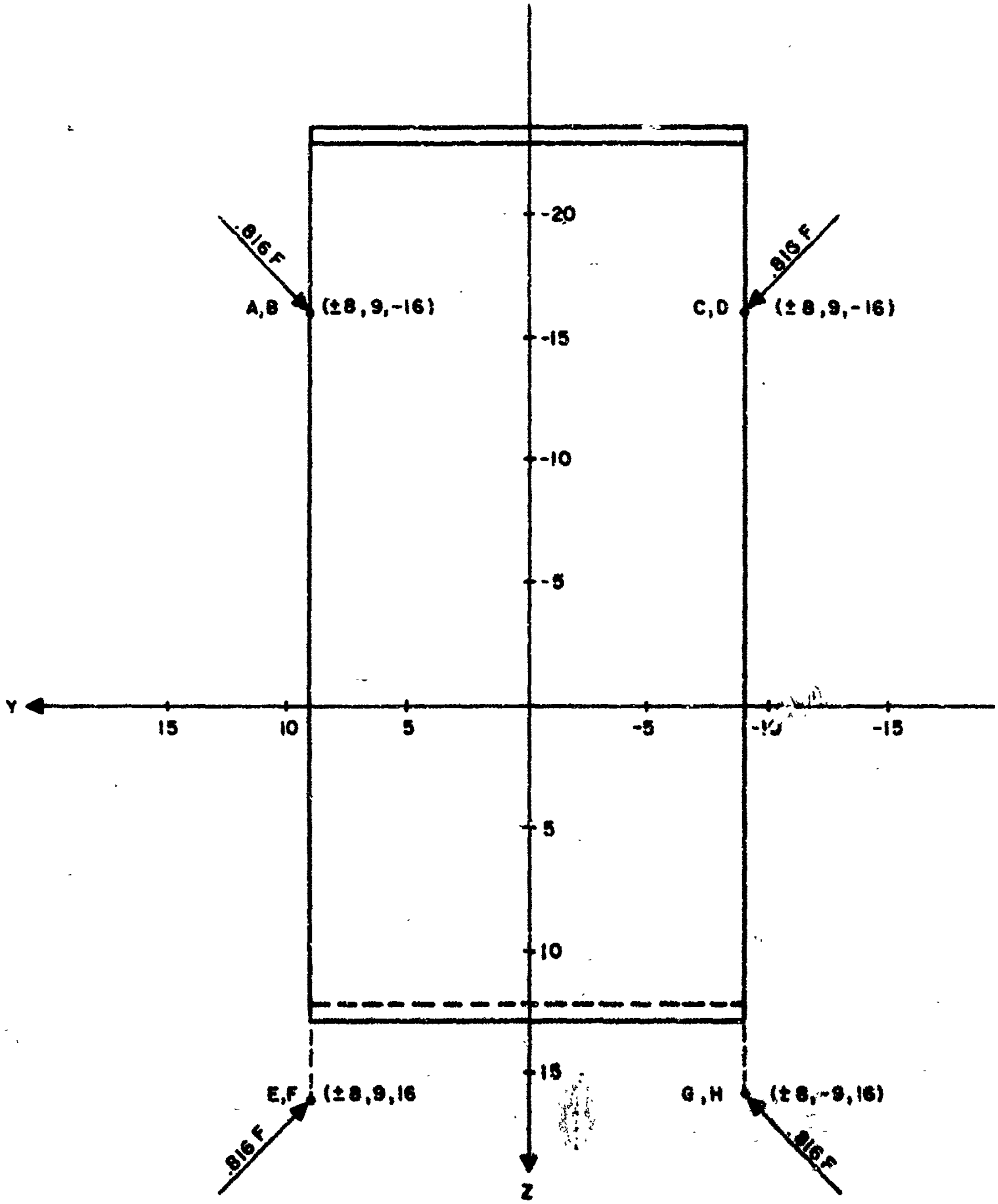


Figure I-3a. Principal Axes for Astronaut Position 1 and 190-lb Backpack (Front View)

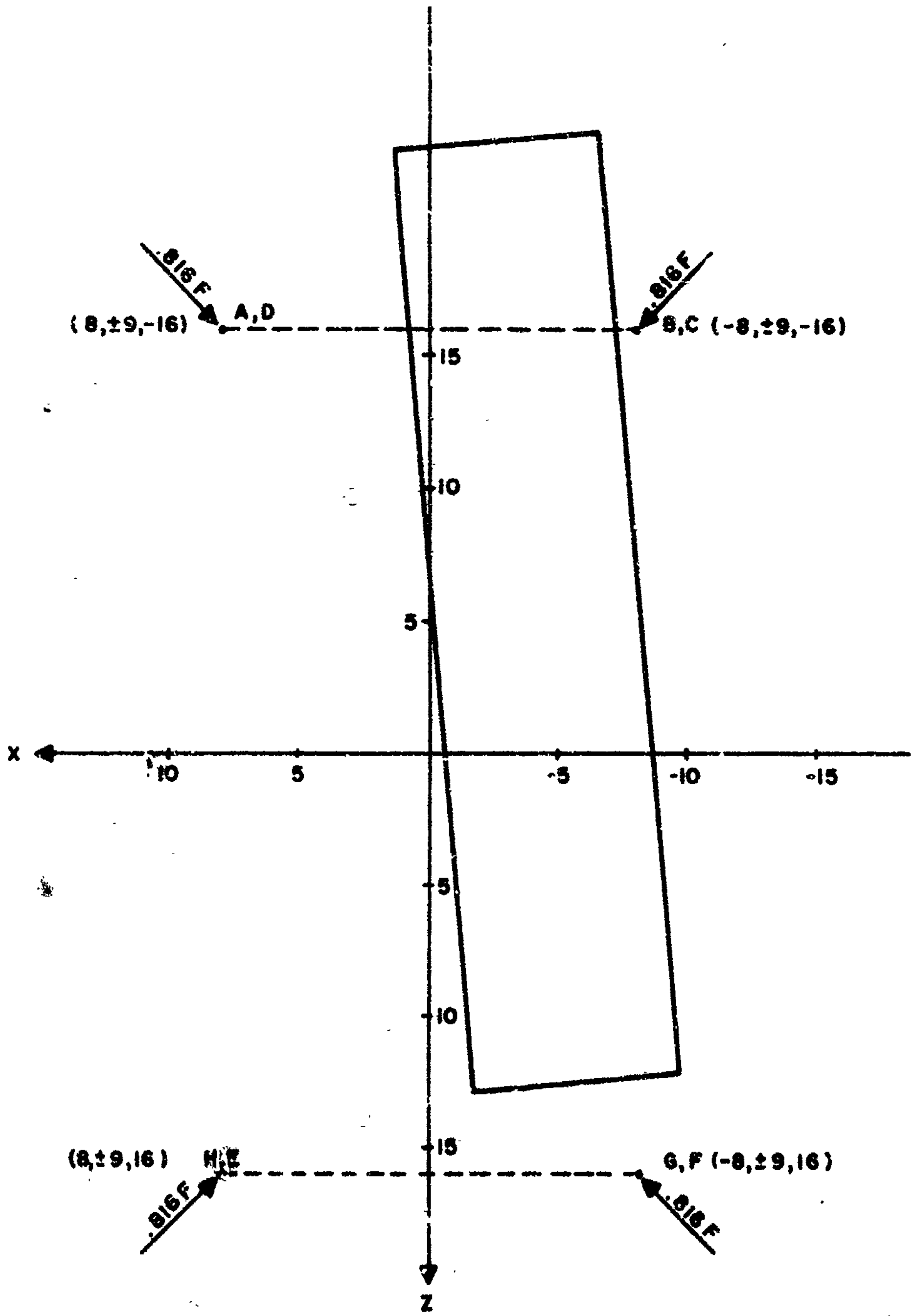


Figure I-3b. Principal Axes for Astronaut Position 1 and 190-lb Backpack (Side View)

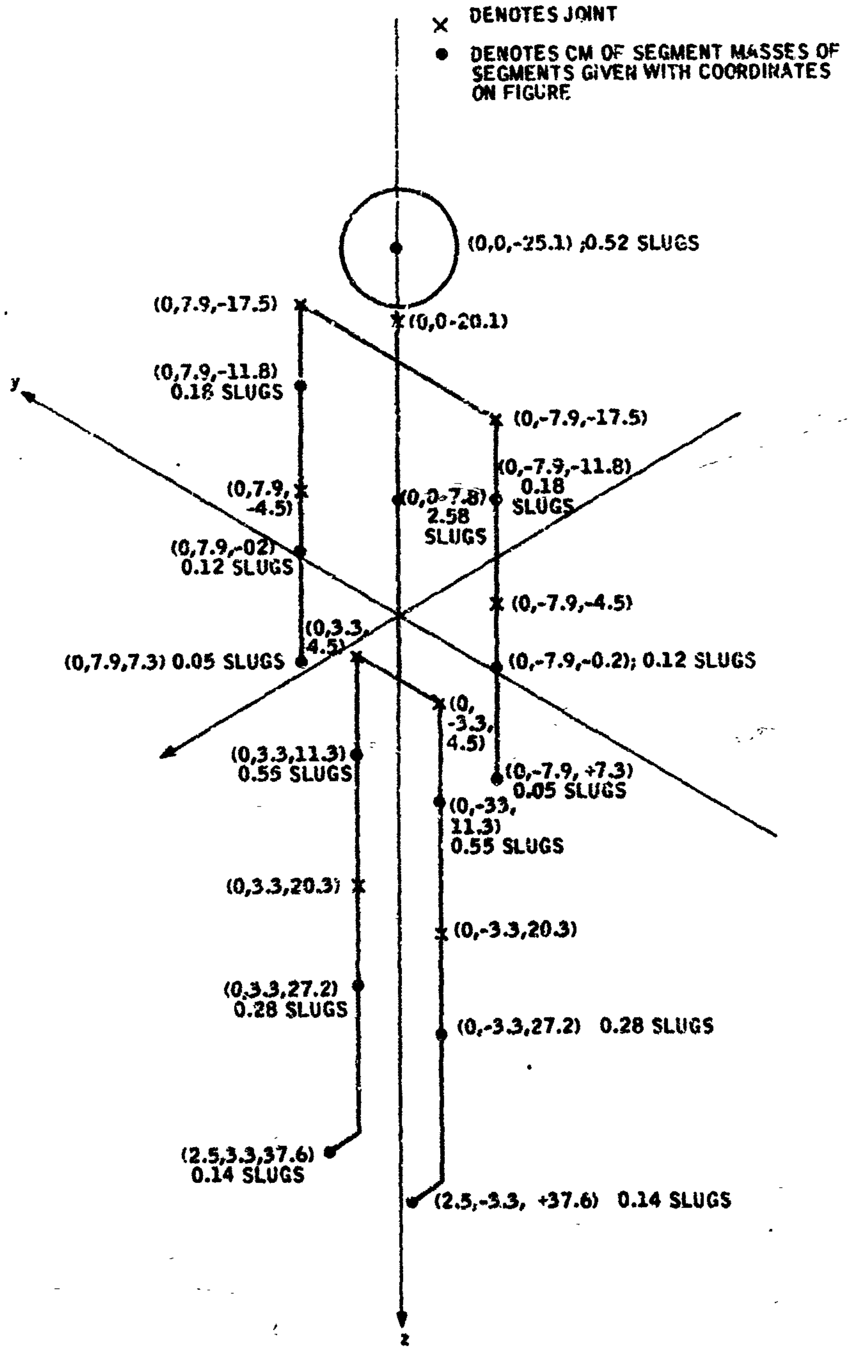


Figure I-4a. Position 1, Standing Erect - Arms at Sides

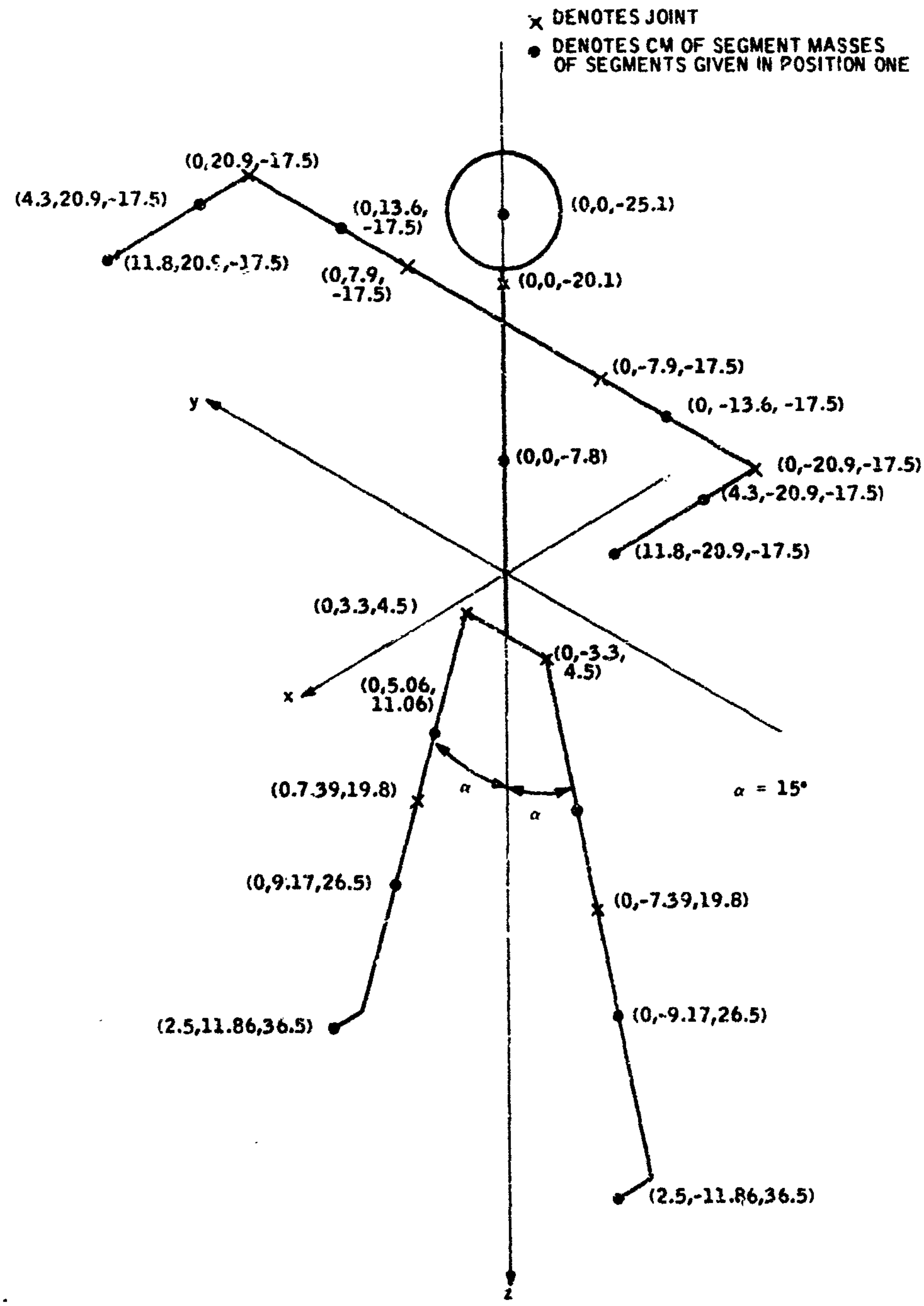


Figure I-4b. Position 2, Standing Erect - Legs Spread - Arms at Rest in Horizontal Plane

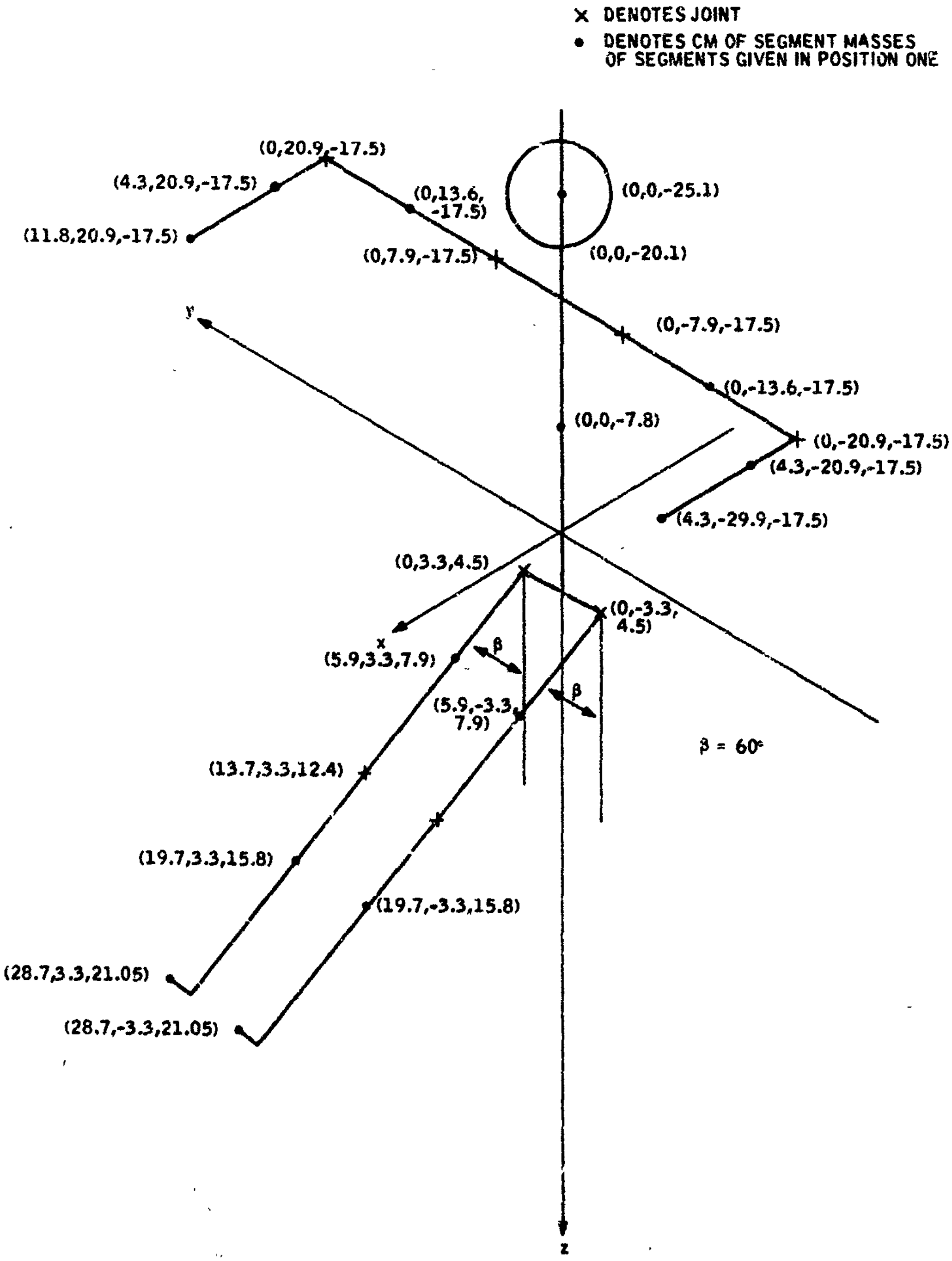


Figure I-4c. Position 3, Arms at Rest in Horizontal Plane - Legs Parallel But Deflected Forward

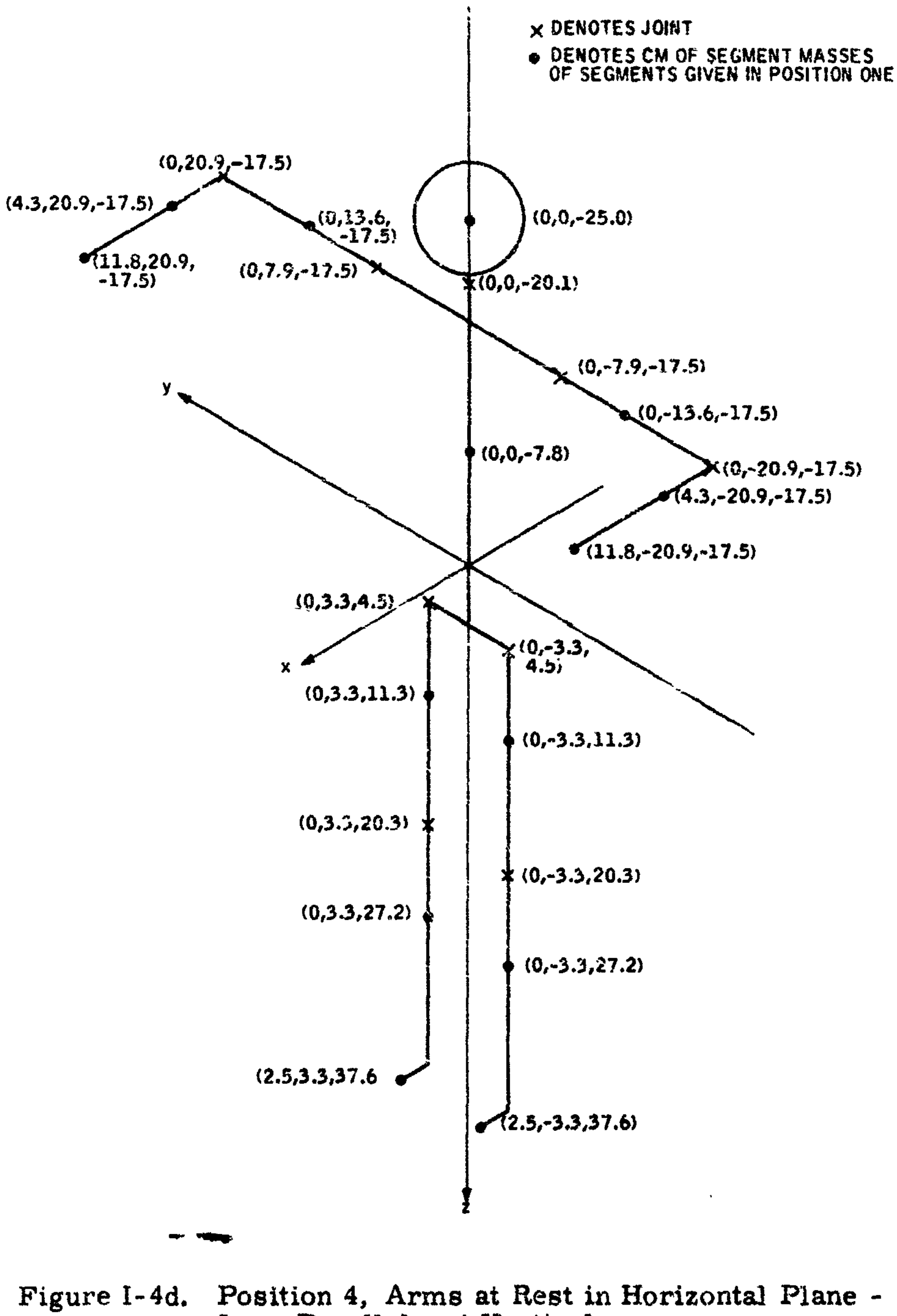


Figure I-4d. Position 4, Arms at Rest in Horizontal Plane - Legs Parallel and Vertical

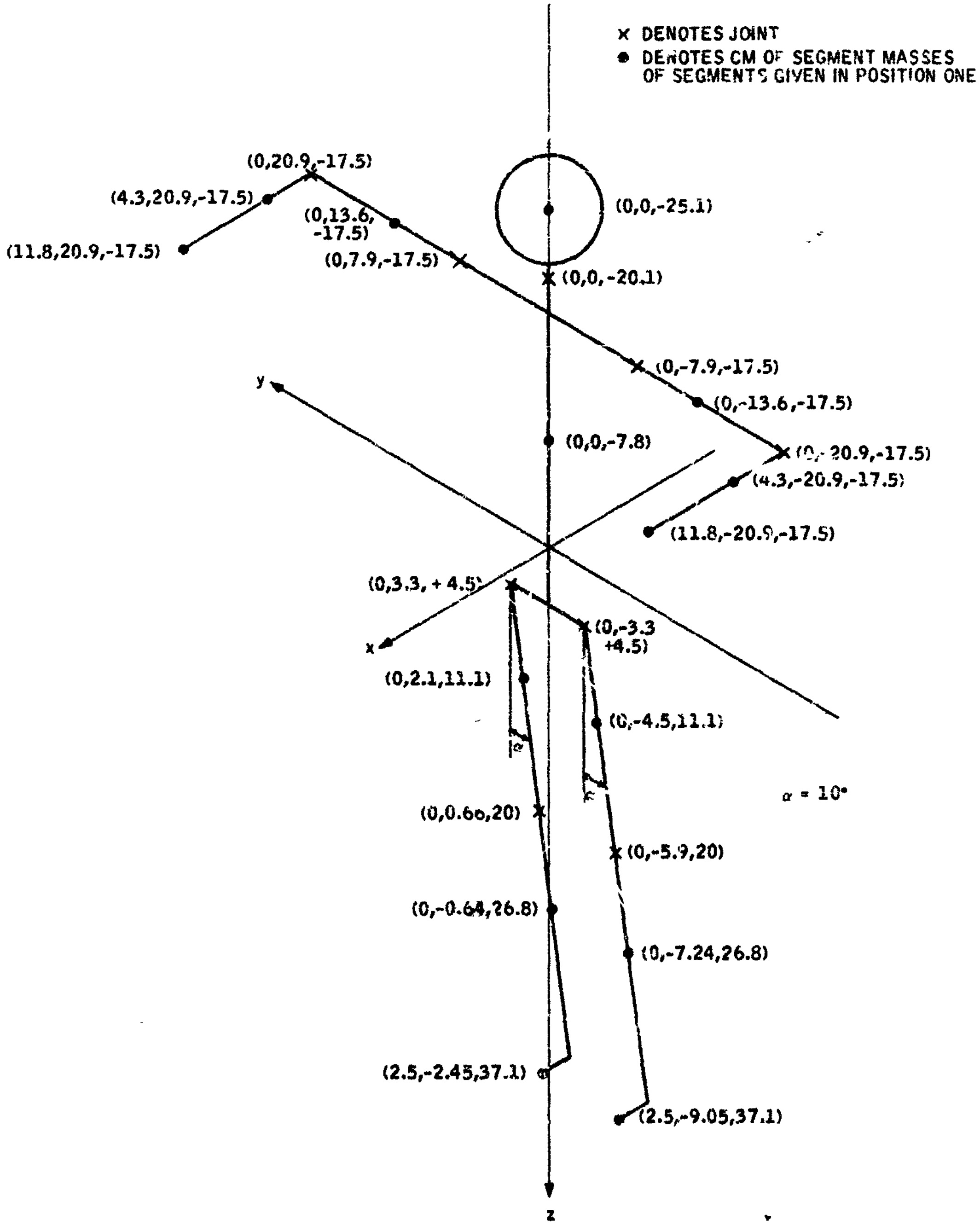


Figure I-4e. Position 5, Arms at Rest in Horizontal Plane - Legs Parallel and Deflected to One Side

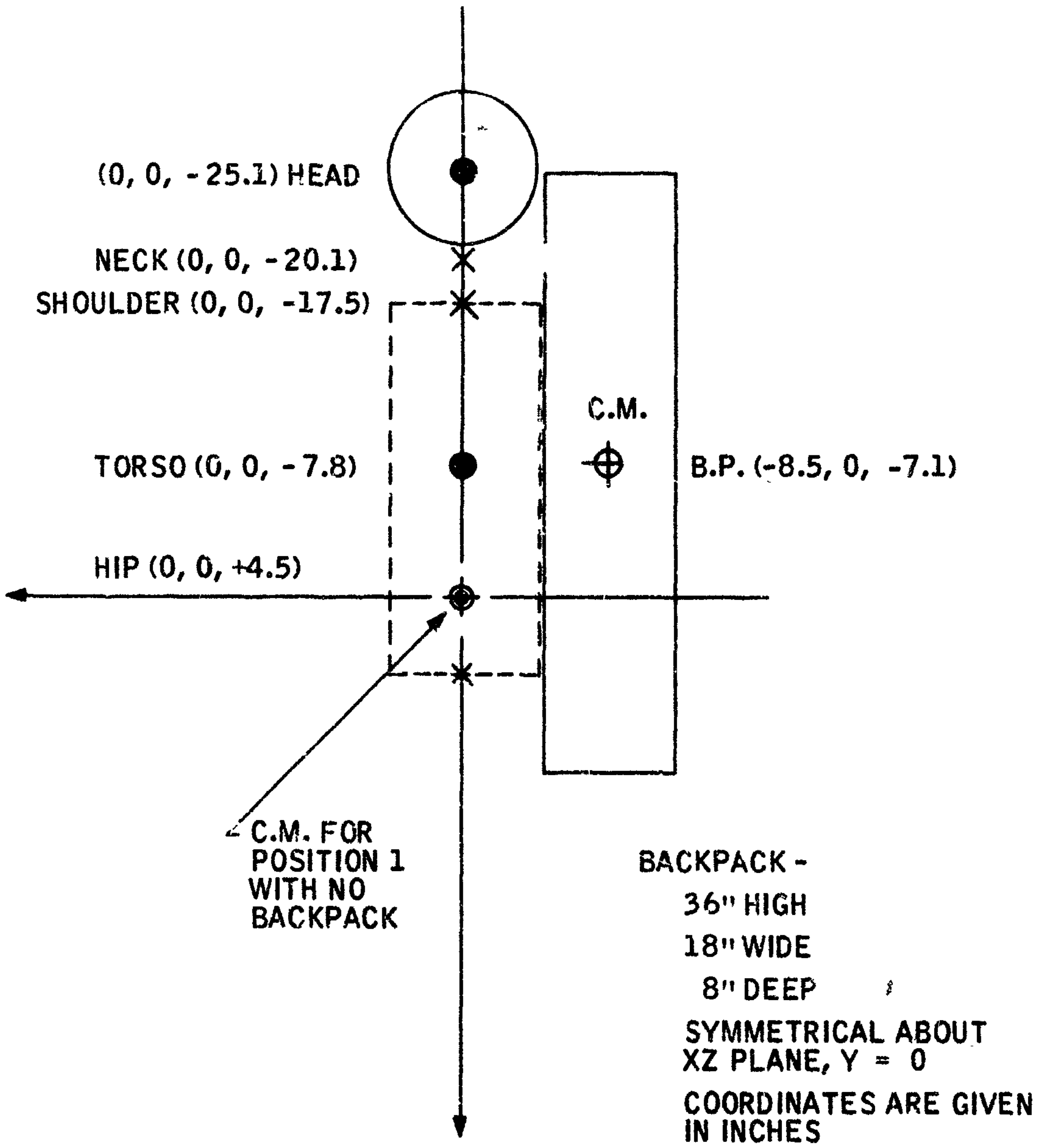


Figure I-5. Relative Locating of Astronaut and Backpack Centers of Mass

SECTION II

SPECIFICATIONS FOR THE ASTRONAUT MANEUVERING UNIT ATTITUDE CONTROL SYSTEM

Sensors and Control Electronics

SECTION II

SPECIFICATIONS FOR THE ASTRONAUT MANEUVERING UNIT ATTITUDE CONTROL SYSTEM

Sensors and Control Electronics

1.0 SCOPE

1.1 This specification defines the design requirements for the sensors and control electronics of the attitude control system (ACS) for the astronaut maneuvering unit (AMU).

1.2 The sensors shall consist of three orthogonally mounted floated integrating gyros together with their mounting and attaching hardware and electrical connections.

1.3 The control electronics shall consist of circuits and components necessary to:

a. Provide all necessary voltages for the ACS except 28-vdc unregulated power which will be furnished from a battery in the AMU.

b. Develop attitude control signals in response to error signals from the sensors.

c. Operate reaction jets in response to inputs from the controller and attitude error circuits.

d. Torque the sensors in response to signals from the controller.

e. Provide drift compensation for the sensors if this is required to meet drift specifications.

2.0 APPLICABLE SPECIFICATIONS AND REFERENCES

2.1 NASA Contract NASw-841

2.2 Section I, "Requirements for the Astronaut Maneuvering Unit Attitude Control System", of this volume (Volume II) of 1781-FR1, 15 June 1964.

2.3 Test Conditions

2.3.1 Operation During Test

In those tests which call for equipment operation, the torquer amplifiers, gyros, power supplies, and switching amplifiers shall be operated according to the following scheme:

2.3.1.1 Simulated loads shall be connected to the jet drivers and power supplies. Simulated loads for the jet drivers are described in Paragraphs 5.2.3.1.5 and 5.2.3.2.8 of Section I of this volume. Simulated loads for power supplies shall draw rated current.

2.3.1.2 Simulated torque commands shall be supplied by external equipment.

2.3.1.3 Each gyro shall be torqued in one direction until the proper jet drivers are actuated. Then it shall be torqued in the opposite direction until the opposite jets fire and so on. Jet drivers shall operate according to the device specification.

2.3.2 Mechanical Vibration

2.3.2.1 Nonoperating -- The equipment shall be attached to the vibration machine by fasteners and attachment points intended for installation in the AMU. The equipment shall be subjected to random vibration at the input power density shown by Curve I of Figure II-1 by a load-equalized shaker for a period of

15 minutes along each of three mutually orthogonal axes. Clippers used to limit peak accelerations shall be not less than 3 sigma. Proper operation shall be established by functional tests according to the applicable device specification both before and after each 15-minute period. The equipment shall also be subjected to two sweeps of the vibration shown by Curve I of Figure II-2 along the same three mutually orthogonal axes as used for random vibration. Time to complete one sweep shall be 7 to 10 minutes. Again proper operation shall be established before and after each session.

2. 3. 2. 2 Operating -- The equipment shall be subjected to the random vibration of Paragraph 2. 3. 2. 1 except with the input power density shown by Curve II of Figure II-1 and to the nonrandom vibration of Paragraph 2. 3. 2. 1 except at the levels shown by Curve II of Figure II-2. During each vibration period, the torquer amplifiers, gyros, power supplies, and switching amplifiers shall be operated according to Paragraph 2. 3. 1.

2. 3. 3 Temperature

2. 3. 3. 1 High Temperature -- The equipment shall be exposed to a test chamber whose walls are maintained at 160°F. Mounting of the equipment shall minimize conduction to and from the walls. After reaching equilibrium, power shall be applied and functional tests shall be completed according to the applicable device specification.

2. 3. 3. 2 Low Temperature -- The equipment shall be exposed to a test chamber whose walls are maintained at -60°F. Mounting of the equipment shall minimize conduction to the walls. After reaching equilibrium, power shall be applied and all functional tests shall be completed according to the applicable device specification.

2.3.4 Radio Frequency Interference Tests

The equipment shall meet the requirements of MIL-I-6181D. During this test, the equipment shall be operated as described in Paragraph 2.3.1.

2.3.5 Acoustic Noise

The equipment shall perform within specification limits during and after exposure to the sound levels specified in Figure II-3. Duration of the test will be 30 minutes -- 10 minutes in each of three mutually orthogonal directions.

2.3.6 Acceleration

The equipment shall be subjected to the test of Procedure I of MIL-E-5272. The acceleration level shall be increased linearly with time from 1 g to 7.5 g's over 300 seconds and held at 7.5 g's for 60 seconds. The acceleration shall be applied along an axis corresponding to the longitudinal axis of the launch vehicle. The 90-degree rotation specified in Paragraph 4.16.1 of MIL-E-5272 shall not be performed. At completion of the test, proper operation of the equipment shall be verified by testing according to the applicable device specification.

2.3.7 Altitude

The equipment shall be mounted to a cold plate with the other five sides insulated. Ambient pressure shall be reduced below 1.5×10^{-5} psia. The equipment shall then be operated according to Paragraph 2.3.1. The cold plate shall be held at 70°F for one hour. At the end of this hour, the cold plate temperature shall be raised from 70°F to 100°F in 30 minutes, held at 100°F for 30 minutes; and then reduced from 100°F to 70°F in 30 minutes. The cold plate temperature shall then be held at 70°F for 90 minutes. The average heat input to the cold plate from the equipment shall not exceed 25 watts per square foot. At this time, the pressure shall be raised to room ambient and proper operation of the equipment established by testing according to the applicable device specification.

2.3.8 Salt Atmosphere

The equipment shall be subjected to Salt Fog Test Method 509 of MIL-STD-810. After 24 hours at room ambient conditions, the equipment shall perform within specification limits.

2.3.9 Sand and Dust

The equipment shall be subjected to Sand and Dust Procedure I of MIL-E-5272 for 50 hours. The equipment shall perform within specification limits at the end of this test.

2.3.10 Fungus

The equipment shall be subjected to Fungus Test Procedure I of MIL-E-5272 unless all materials used in fabrication are non-nutrients to fungi. At the completion of this test, the equipment shall perform within specification limits.

2.3.11 Humidity

The equipment shall be exposed to 100 percent relative humidity for 48 hours. The temperature shall be held between 65 and 85°F. At the end of this period, the external surfaces of the equipment (including external connectors) shall be wiped dry and then exposed to 65 to 85°F with relative humidity less than 80 percent for 24 hours. At the end of this period, the equipment shall perform within specified limits.

2.3.12 Shock

When subjected to 50-g shock along the axis designated by the device specification, the equipment shall not break loose from its mounts and all internal parts shall be contained within the equipment. The shock shall be applied as a sinusoidal pulse of 11 ms duration. The equipment need not operate after the test.

3.0 DESIGN REQUIREMENTS

3.1 <u>Sensors</u>

3.1.1 General Description

The gyro shall have a single degree of freedom with limited gimbal freedom. It shall be designated primarily for hard-mounted, strapped-down applications. The unit shall include a means of compensation for all gravity-insensitive torques. The operating temperature of the unit shall not exceed 200°F.

3.1.2 Passive Electrical Characteristics

The following nominal values are given as a guide or an indication of the expected mean.

3.1.2.1 Spinmotor Synchronous Impedance (at 400 cps): 75 + J130 ohms, line to neutral.

3.1.2.2 Signal Generator Impedance (at 400 cps):

Primary	49 + J17 ohms
Secondary	980 + J980 ohms

3.1.2.3 Compensator Impedance (at 400 cps): 13 + J13 ohms

3.1.2.4 Torque Generator:

Resistance	170 ohms
Inductance	5 millihenries

3.1.3 Mechanical and Dynamic Characteristics

3.1.3.1 Weight: 1.25 pounds maximum

3.1.3.2 Dimensions: 4.25 inches maximum length by 2.25 inches maximum diameter

3.1.3.3 Mounting and Alignment (flange mount with index notch):

Notch alignment error	3 mr maximum
Flange perpendicularity error	2 mr maximum

3.1.3.3.1 The gyro mounting structure shall provide a common heat sink between the gyros to minimize the number of temperature control components required.

3.1.3.3.2 Heat dissipation of electronic components will be used where possible as heat supply sources to the gyro mounting structure to minimize the temperature control operating power.

3.1.3.3.3 Heat transfer between the sensor package and the AMU structure will be controlled for minimum temperature control operating power.

3.1.3.3.4 Maximum power dissipation of the sensor package to the AMU mounting structure shall be 25 watts per square foot.

3.1.3.4 Drift and Maximum Rates of Temperature: The gyro shall have a maximum drift rate (gravity insensitive) of 1 deg/hr after having first been trimmed at normal operating temperature and after completing 3 warm-up cycles from a -30°F ambient condition.

3.1.3.5 Input Axis Freedom: The gyro shall have an input axis freedom of ±14 degrees minimum, ±20 degrees maximum.

3.1.3.6 An SN-20-20 PS Continental connector shall be used.

3.1.4 Performance Characteristics

3.1.4.1 Spinmotor: The spinmotor shall be a three-phase synchronous motor designed to operate at 26 v rms, 400-cps nominal line-to-line voltage and shall maintain synchronous speed down to 15 v rms, 400 cps line-to-line. The spinmotor should not draw more than 150 ma from each phase when in synch and running from a 3-phase, 26 v rms line-to-line voltage system.

3.1.4.2 Signal Generator: The primary excitation of the signal generator shall be 26 v rms, 400 cps. When excited from such a source and with the secondary loaded with 15 k ohms the primary shall draw no more than 55 ma rms from the 26 v rms source. The signal generator shall have a scale factor of 12.5 v rms per radian ±5 percent.

3.1.4.3 Torque Generator: The torque generator shall be of the permanent magnet type (which requires no excitation) and have a control parameter of 0.3 deg/sec/ma ±5 percent nominal, with a linearity of 0.2 percent for torque rate versus torquer current from 0 to ±100 ma, and a linearity of 1 percent for torque rate versus input angle between 0 and ±50 milliradians.

3.1.4.4 Transfer Function Linearity: The incremental slope of the gyro transfer function shall not deviate by more than 10 percent from the mean over the entire range of gimbal travel.

3.1.4.5 Phasing: Gyro axis and positive rotations are defined in Figure II-4. With the spinmotor turning in a positive direction, positive rotation of the gyro about the input axis shall cause positive rotation of the gimbal. Positive torque from the torque generator shall also cause positive rotation of the gimbal.

3.1.4.6 Spinmotor Rotation Detector: The gyro shall contain a spinmotor rotation detection device capable of supplying a 10-kilohm load with a minimum signal of 200 millivolts rms, 800 cps when the gyro spinmotor has reached synchronous speed.

3.1.4.7 Drift: The gyro shall after environmental exposure per Paragraph 2.3 exhibit no more than the following categorized drift rates:

Acceleration Insensitive	1 deg/hr maximum
Acceleration Sensitive	3 deg/hr/g
Acceleration^2 Sensitive	0.02 deg/hr/g^2 rms
Random Drift Rate	0.05 deg/hr
Elastic Restraint	1 deg/hr/deg IA to ± 3.5 deg IA 1.5 deg/hr/deg IA to ± 10 deg IA

3.1.4.8 Induced Voltage:

3.1.4.8.1 Sensing Element -- With standard excitation applied to the spinmotor, signal generator, and operating heater, the open circuit rms voltage induced in the temperature-sensing element shall not exceed 3.0 mv.

3.1.4.8.2 Motor and Heater Noise -- With the standard excitation applied to the spinmotor and operating heater and all circuitry removed from the signal generator, primary and torque generator, the voltage induced in the open circuit signal generator secondary shall not exceed 5 mv rms.

3.1.4.8.3 Signal Generator Null -- With the gyro at operating temperature and standard excitation applied to the spinmotor, signal generator primary, and operating heater, the null or minimum signal generator secondary voltage shall not exceed:

400 cps component (quadrature only)	2.0 mv rms
800 cps component	3.5 mv rms
2400 cps component	5.0 mv rms

3.2 Control Electronics

3.2.1 General

The electronics will consist of all logic and signal processing circuitry necessary to operate eight reaction jets.

3.2.2 Details

3.2.2.1 Interfaces

3.2.2.1.1 The electronics shall operate eight propulsion jets in response to controller commands and attitude errors. Design characteristics of the valves can be found in Paragraphs 5.2.3.1 and 5.2.3.2 of Section I of this volume.

3.2.2.1.2 The controller shall supply jet operating power to the electronics. The controller will also supply six translational command signals and 19 gyro torquing commands.

3.2.2.1.3 The AMU power system will supply unregulated 28-vdc battery power. Maximum power drain shall be 360 watts. This includes electronics, gyros, heaters, and six reaction jets.

3.2.2.1.4 The sensors will supply three attitude error signals to the control electronics. The control electronics will supply torquing power, spinmotor power and signal generator excitation to the sensors.

3.2.3 Electrical Design

The electronics may be divided into three sections for discussion of their functional requirements. These need not represent spatial, functional, or modular subdivisions of the actual device. The sections are torquer amplifiers, attitude error circuits, and thrust logic.

3.2.3.1 Torquer Amplifiers -- The input to the torquer amplifiers will be the torquer commands from the controller. The output of the torquer amplifiers will be voltages or currents of the proper sense and magnitude to the proper gyro.

3.2.3.2 Attitude Error Circuits -- The input to the attitude error circuits will be the output of the sensor signal generators. The output of the attitude error circuits will be six logic signals designated:

I - Positive yaw error
J - Negative yaw error
K - Positive pitch error
L - Negative pitch error
M - Positive roll error
N - Negative roll error

The Boolean notation used throughout will be:

1 represents the transmitting state (in particular when the logic variable representing a thrust jet is equal to 1, the jet is on)

0 represents the blocking state (jet off)

J' is the complement of J ("not J")

3.2.3.2.1 The pulse circuit portion of the attitude error circuits will behave in the following manner:

I, K, or M = 1 for 17 milliseconds whenever the appropriate attitude error reaches +12 mr

J, L, or N = 1 for 17 milliseconds whenever the appropriate attitude error reaches -12 mr

3.2.3.2.2 Each of three pseudo rate circuits will consist of two electronic logic switches and associated feedback circuitry. The description that follows uses the terminology of d-c switching circuits but is not intended to prejudice the circuit design. The block diagrams are intended to indicate function rather than circuit details. Instead of voltage levels, error magnitude will be specified in milliradians of input angular error.

When the respective input error reaches +17 mr with an initial feedback voltage of zero, the I, K, and M switches shall switch I, K, and M from 0 to 1. The I, K, and M switches will also apply a negative step delayed 5 ms to a feedback network with a transfer function of T/(S+T) where $T = 1\ sec^{-1}$.

When the respective input error reaches -17 mr with an initial feedback voltage of zero, the J, L, and N switches shall switch J, L, and N from 0 to 1. The J, L, and N switches shall at the same time apply a positive step input delayed 5 ms to the feedback network.

3.2.3.2.3 Upon a logic input from the controller the deadband limits of Paragraph 3.2.3.2.2 shall be switched from 17 mr to 160 mr.

3.2.3.3 Thrust Logic -- Power to operate the propellant valves shall be supplied to the control electronics from the controller. When this power is on, the jets shall operate according to the last set of Boolean equations in this paragraph.

Nomenclature:

$$\left.\begin{array}{l} A \\ B \\ C \\ D \\ E \\ F \\ G \\ H \end{array}\right\} \text{Jets}$$

The location and line of action of these jets are shown in Section I, Figure I-3 of this volume.

O - +X (forward) thrust command
P - -X (aft) thrust command
Q - +Y (right) thrust command
R - -Y (left) thrust command
S - +Z (down) thrust command
T - -Z (up) thrust command

Inputs to the thrust logic from the controller

$$\begin{aligned}
A &= (P+R+S)\, I'K'N' + (J+L+M)\, O'Q'T' \\
B &= (O+R+S)\, J'L'N + (I+K+M)\, P'Q'T' \\
C &= (O+Q+S)\, I'L'M' + (J+K+N)\, P'R'T' \\
D &= (P+Q+S)\, J'K'M' + (I+L+N)\, O'R'T' \\
E &= (P+R+T)\, I'L'M' + (J+K+N)\, O'Q'S' \\
F &= (O+R+T)\, J'K'M' + (I+L+N)\, P'Q'S' \\
G &= (O+Q+T)\, I'K'N' + (J+L+M)\, P'R'S' \\
H &= (P+Q+T)\, J'L'N' + (I+K+M)\, O'R'S'
\end{aligned}$$

Insofar as possible, the failure modes with the highest probability shall fail in such a way as to make jet actuation less likely.

3.2.4 Mechanical Design

The control electronics shall weigh less than 3 pounds and occupy no more volume than 85 cubic inches. Modular construction shall be employed where practicable.

3.2.5 Reliability

The reliability goal for the control electronics is 0.9987 for a four-hour mission. Reliability is defined as the probability the control electronics will perform the functions described in Paragraph 3.2.3.

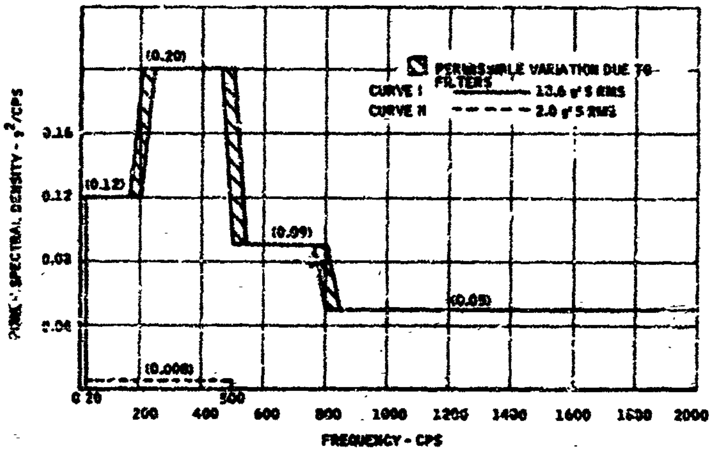


Figure II-1. Input Power Density for Random Vibration Test

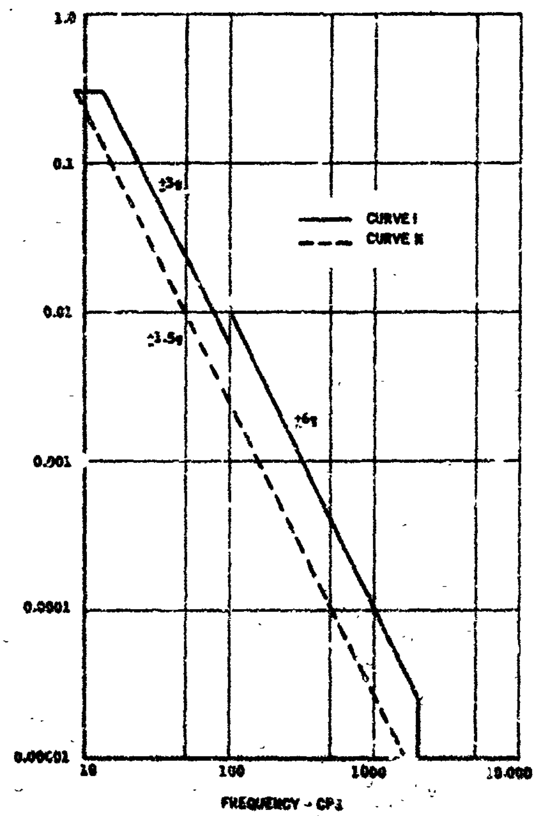


Figure II-2. Acceleration Level for Vibration Test

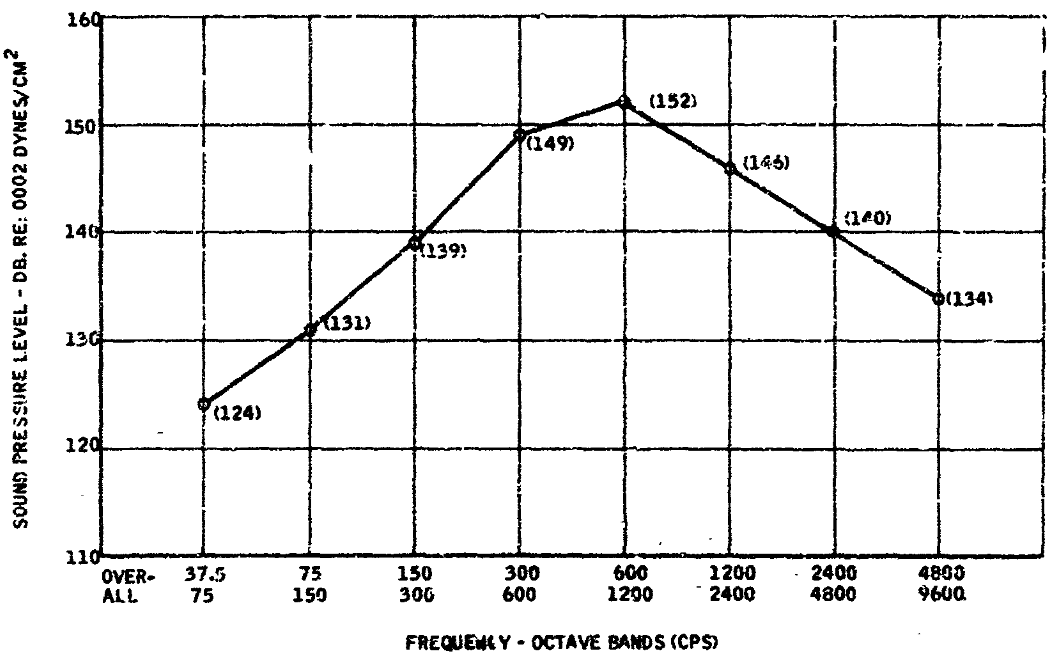


Figure II-3. Acoustic Noise Level for Acoustic Noise Test

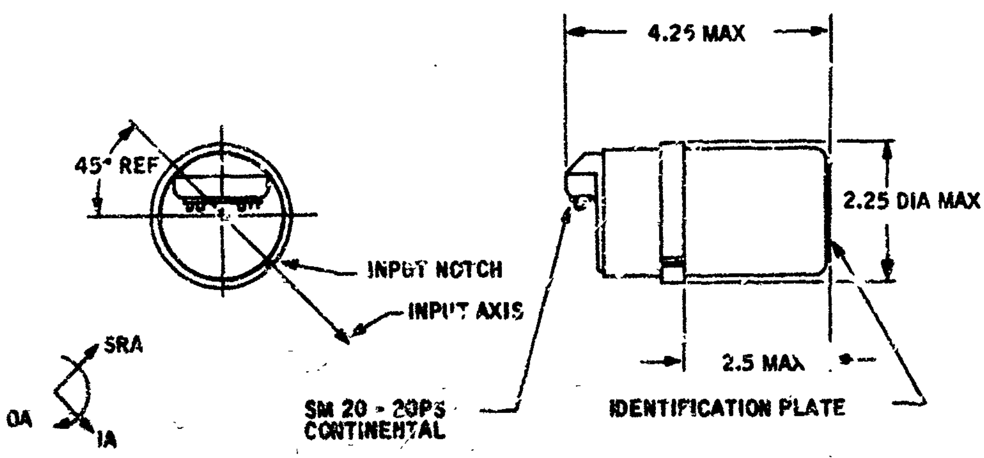


Figure II-4. Gyro Axes

SECTION III

PERFORMANCE SPECIFICATION FOR THE ASTRONAUT MANEUVERING UNIT ATTITUDE CONTROL SYSTEM CONTROL ELECTRONICS

SECTION III

PERFORMANCE SPECIFICATION FOR THE ASTRONAUT MANEUVERING UNIT ATTITUDE CONTROL SYSTEM CONTROL ELECTRONICS

1.0 SCOPE

This specification defines performance requirements for the control electronics of the attitude control system (ACS).

1.1 The control electronics shall consist of circuits and components necessary to:

a. Develop attitude control signals in response to sensor error signals.

b. Operate reaction jets in response to sensor error signals and commands from the controller.

c. Torque sensors in response to controller command signals.

d. Control sensor thermal environment.

e. Provide sensor drift compensation.

f. Provide necessary voltages for sensor and electronics functioning from the unregulated 28 vdc AMU battery.

1.2 Electrical Design

1.2.1 Functional Requirements

The ACS control electronics is divided physically and functionally into the following parts:

a. Control Logic and Temperature Control Amplifier: Honeywell Drawing No. SK92529*

b. ACS Axis Computers and Sensor Torquer Amplifiers:

Pitch Axis: Honeywell Drawing No. SK92531

Roll Axis: Honeywell Drawing No. SK92532

Yaw Axis: Honeywell Drawing No. SK92533

c. Reaction Jet Drivers: Honeywell Drawing No. SK92530

d. Power Supply: Honeywell Drawing No. SK92534

1.2.1.1 Control Logic and Temperature Control Amplifier (SK92529)

1.2.1.1.1 The control logic shall accept digital inputs of the form "1" = +6 vdc and "0" = 0 vdc from the controller and the ACS axis computers. The control logic shall perform the logic functions described in the following Boolean equations:

$$A = (P+R+S)\, I'K'N' + (J+K+M)\, O'Q'T'$$
$$B = (O+R+S)\, J'L'N' + (I+K+M)\, P'Q'T'$$
$$C = (O+Q+S)\, I'L'M' + (J+K+N)\, P'R'T'$$
$$D = (P+Q+S)\, J'K'M' + (I+L+N)\, O'R'T'$$
$$E = (P+R+T)\, I'L'M' + (J+K+N)\, O'Q'S'$$
$$F = (O+R+T)\, J'K'M' + (I+L+N)\, P'Q'S'$$
$$G = (O+Q+T)\, I'K'N' + (J+L+M)\, P'R'S'$$
$$H = (P+Q+T)\, J'L'N' + (I+K+M)\, O'R'S'$$

*Honeywell drawings referred to in this volume are contained in Volume III of this final report.

Where A, B, C, D, E, F, G, and H represent the reaction jets:

I - positive yaw error	J - negative yaw error
K - positive pitch error	L - negative pitch error
M - positive roll error	N - negative roll error
O - +x thrust command	P - -x thrust command
Q - +y thrust command	R - -y thrust command
S - +z thrust command	T - -z thrust command

B′, for example, denotes the complement of B - "not B"

1.2.1.1.2 The temperature control amplifier shall continuously monitor the sensor package temperature. During normal operation it shall maintain the gyros at their nominal operating temperature (+180°F). The temperature control amplifier shall continuously apply heater power during warm-up, until the sensor package temperature reaches nominal operating temperature (+180°F).

1.2.1.2 Attitude Control System Axis Computers and Sensor Torque Amplifiers

1.2.1.2.1 Attitude Control System Axis Computers

1.2.1.2.1.1 Synchronous Mode: The control electronics shall prevent reaction jet firing due to computer action and shall maintain the sensors within 1 degree of null attitude for all input attitude rates less than 20 deg/sec. This is the normal mode of the ACS; that is, no input signal shall be required to establish this mode other than the application of primary electrical power. No controller command inputs shall be allowed during this mode.

1.2.1.2.1.2 Normal Limit Operate Mode: The control computer shall provide attitude stabilization within the specified limits of Section I of this volume for the various program profile work tasks. The control computer, upon controller command, shall produce translational thrust along the axes of the unit in both senses. The control computer shall produce three levels of rotational rate in both senses about each axis in response to controller command. Each rotational rate, in each sense about each axis, is in response to a unique and distinct controller command input to the ACS. The translational thrust and rotational rates shall persist for the duration of the controller command input to the ACS.

1.2.1.2.1.3 Extended Limit Operate Mode: In response to a controller command, the ACS control computer shall expand the attitude limit cycle deadband. Responses to translational and rotational controller commands shall remain unchanged; however, rotational command responses may appear different due to the wide deadband.

1.2.1.2.1.4 Emergency Mode: Solenoid 28 vdc power and the operate signal shall be removed from the ACS computers. Removal of these voltages shall prevent reaction jet firing and shall place the ACS in synchronous mode.

1.2.1.2.2 Sensor Torque Amplifiers

The sensor torquer amplifiers are required to torque the sensors in response to digital inputs from the controller.

1.2.1.3 Reaction Jet Drivers (SK92530)

The reaction jet drivers are required to switch the operating current of the reaction jet solenoid valves in response to the outputs of the command logic.

1.2.1.4 Power Supply (SK92534)

The power supply is required to furnish all power for the operation of the sensor and control electronics except unregulated 28 vdc.

2.0 APPLICABLE SPECIFICATIONS AND REFERENCES

2.1 Section I, "Requirements for the Astronaut Maneuvering Unit Attitude Control System," of this volume (Volume II) of 1781-FR1, 15 June 1964

2.2 Section II, "Specifications for the Astronaut Maneuvering Unit Attitude Control System Sensors and Control Electronics," of this volume (Volume II) of 1781-FR1, 15 June 1964

2.3 Diagrams (see Volume III)

SK92529	SK92532
SK92530	SK92533
SK92531	SK92534

3.0 DETAIL COMPONENT REQUIREMENTS

3.1 <u>Control Logic and Temperature Control Amplifier (SK92529)</u>

3.1.1 Control Logic

3.1.1.1 Input Characteristics

3.1.1.1.1 Power -- The input to pin 8 of SK92529 shall be +6 ± 0.1 vdc at 55 ma maximum current with a maximum ripple of 0.2 v rms and maximum source impedance of 3 ohms.

3.1.1.1.2 Signal -- The input signals to pins I, J, K, L, M, N, O, P, Q, R, S, and T of SK92529, shall be of the digital form "1" equals +6 ± 0.6 vdc with a maximum source impedance of 4.5 kilohms. "0" equals 0 ± 0.6 vdc from a 4.5 kilohm source impedance.

3.1.1.1.3 Noise -- The input signal noise content shall have an E^2t product less than 0.5×10^{-6} v^2 seconds for frequencies above 800 cps, where v is the peak amplitude of the noise voltage and t is the pulse duration or $1/4\pi f$. The input signal shall contain not more than 0.2 v rms each of 400- and 800-cps ripple.

3.1.1.2 Output Characteristics

3.1.1.2.1 Power -- The output shall display a maximum source impedance of 4.5 kilohms.

3.1.1.2.2 Signal -- The output of this device shall be +6 ± 0.6 vdc for "0" and 0 ± 0.6 vdc for "1".

3.1.1.2.3 Noise -- The noise contained in the output of this unit shall be 0.3 v peak and of less than 10 microseconds pulse duration, and shall contain not more than 0.2 v rms each of 400- and 800-cps ripple.

3.1.1.3 Functional Requirements: The unit shall accept inputs of the form specified in Paragraph 3.1.1.1 and provide outputs per 3.1.1.2 according to the following rules expressed as digital logic equations:

$$A = (P+R+S)\ I'K'N' + (J+L+M)\ O'Q'T'$$
$$B = (O+R+S)\ J'L'N' + (I+K+M)\ P'Q'T'$$
$$C = (O+Q+S)\ I'L'M' + (J+K+N)\ P'R'T'$$
$$D = (P+Q+S)\ J'K'M' + (I+L+N)\ O'R'T'$$
$$E = (P+R+T)\ I'L'M' + (J+K+N)\ O'Q'S'$$
$$F = (O+R+T)\ J'K'M' + (I+L+N)\ P'Q'S'$$
$$G = (O+Q+T)\ I'K'N' + (J+L+M)\ P'R'S'$$
$$H = (P+Q+T)\ J'L'N' + (I+K+M)\ O'R'S'$$

where

A B C D E F G H	to jet drivers	The location and line of action of these jets are shown in Figure I-3, Section I of this volume.

I - Positive yaw error

J - Negative yaw error

K - Positive pitch error

L - Negative pitch error

M - Positive roll error

N - Negative roll error

O -	+X (forward)	thrust command	Inputs to the thrust logic from the controller
P -	-X (aft)	thrust command	
Q -	+Y (right)	thrust command	
R -	-Y (left)	thrust command	
S -	+Z (down	thrust command	
T -	-Z (up)	thrust command	

3.1.2 Temperature Control Amplifier

3.1.2.1 Input Characteristics

3.1.2.1.1 Power --

3.1.2.1.1.1 Pin 1 of SK92529: +12 ± 0.2 vdc at 12.5 ma from a 3-ohm (max) source containing less than 0.2 v rms each of 400 and 800 cps.

3.1.2.1.1.2 Pin 4 of SK92529: -12 ± 0.2 vdc at 18 ma from a 3-ohm (max) source containing less than 0.2 v rms each of 400 and 800 cps.

3.1.2.1.1.3 Pin 8 of SK92529: +6 ± 0.1 vdc at 5 ma from a 3-ohm (max) source containing less than 0.1 v rms each of 400 and 800 cps.

3.1.2.1.1.4 Pin 5 of SK92529: 28 ± 4 vdc at 24 ma from a source impedance of less than 5 ohms. Voltage source excursions below 24 vdc shall be limited to 15×10^{-6} seconds.

3.1.2.1.1.5 Pins 2 and 3 of SK92529: +6 v ground, +12 v ground, -12 v ground, and +28 v ground shall be tied together.

3.1.2.1.2 Signal -- This unit requires a temperature-sensitive resistor which is 780 ohms at +180°F and changes 1.5 ohms per degree F. This sensor element connects to a bridge to provide the needed temperature control error signal.

3.1.2.1.3 Noise -- The sense element shall have less than 750 millivolts rms each of 400 and 800 cps.

3.1.2.2 Output Characteristics

The maximum base drive to the sensor package heater element driver transistor from the temperature control amplifier shall be at least 18 ma. The noise in this signal shall be essentially that in the 28-vdc primary power source. With a 1.3-ohm resistor connected between pins 1 and 2 of SK92529 and less than 770 ohms between pins 6 and 9, a minimum of 18 ma current shall flow through the 1.3-ohm resistor; when the resistance between pins 1 and 2 is greater than 790 ohms, less than 10×10^{-6} amperes shall flow through the 1.3-ohm resistor.

3.2 Attitude Control System Axis Computer and Sensor Torquer

3.2.1 Attitude Control System Axis Computers

The following requirements pertain to the pitch (SK92532), roll (SK92531), and yaw (SK92533) ACS axis computers.

3.2.1.1 Input Characteristics

3.2.1.1.1 Power --

3.2.1.1.1.1 Pin 3: +12 ± 0.5 vdc at 8.5 ma maximum from a 3-ohm (maximum) source impedance containing less than 0.2 v rms each of 400 and 800 cps.

3.2.1.1.1.2 Pin 1: -12 ± 0.5 vdc at 21 ma maximum from a 3-ohm (maximum) source impedance containing less than 0.2 v rms each of 400 and 800 cps.

3.2.1.1.1.3 Pin 23: +6 ± 0.25 vdc at 27 ma maximum from a 3-ohm (max) source impedance containing less than 0.1 v rms each of 400 and 800 cps.

3.2.1.1.1.4 Pin 2: -6 ± 0.25 v rms 400 cps square wave at 1 ma maximum from a 0.15-ohm (max) source impedance. The square wave shall have a rise and fall time of less than 100 microseconds.

3.2.1.1.2 Signal --

3.2.1.1.2.1 Analog Attitude Signal: The input shall be a 400 cps square wave with a rise and fall time of less than 100 microseconds. The input waveform shall be in or out of phase with the waveform on pin 2. The input shall be applied between pins 20 and 21. An in-phase waveform shall denote pin 20 in phase with pin 2. The input signal shall be applied from a source of 1.4 kilohms or less impedance.

3.2.1.1.2.2 Digital Control Signals:

Operate Signal: +6 ± 0.25 vdc at 0.1 ma maximum at pin 4

Standby Signal: 0 ± 0.25 vdc at 0.001 ma maximum at pin 4

Range or Deadband Control:

17 mr: 0 ± 0.25 vdc at 0.001 ma at pin 22

160 mr: +6 ± 0.25 vdc at 10 ma at pin 22

3.2.1.2 Output Characteristics

3.2.1.2.1 Power -- The output of this unit shall be either 0 ± 0.5 vdc or +6 ± 0.5 vdc from a 4.5 kilohm source impedance.

3.2.1.2.2 Signal --

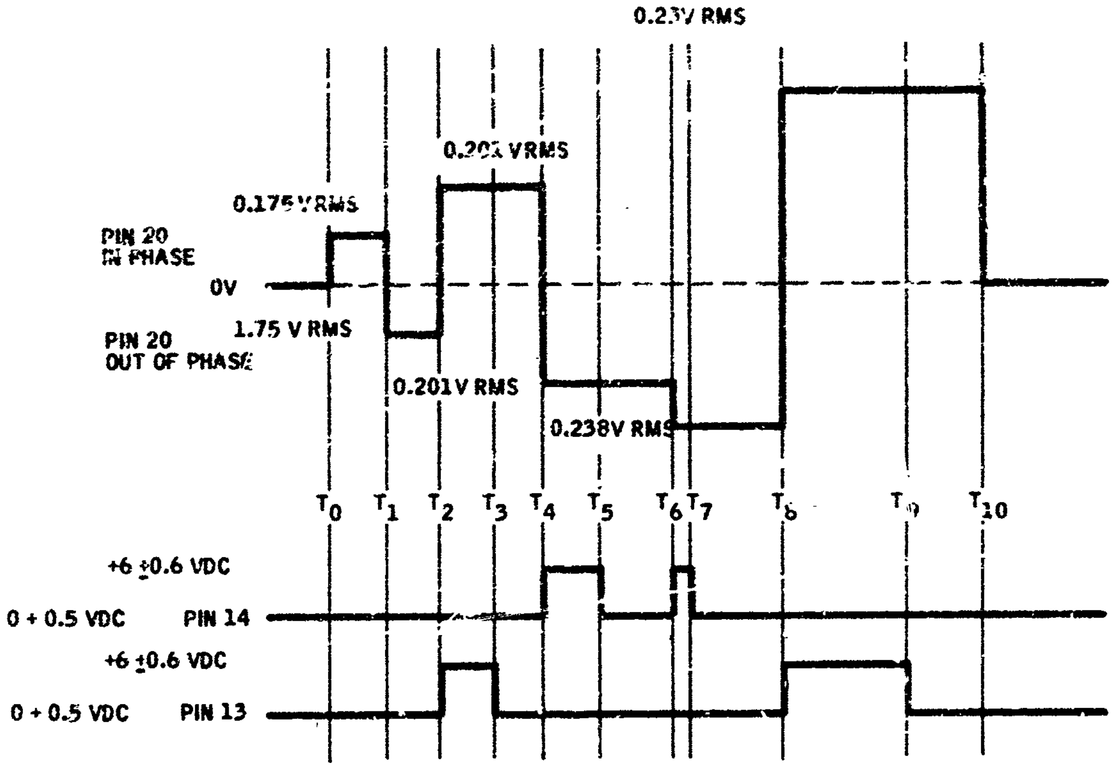
3.2.1.2.2.1 Normal Limit Operate Mode: The output between pins 13 and 14 shall show the relationship indicated in Figure III-1 with the input between pins 20 and 21, with +6 vdc applied to pin 4 and 0 vdc applied to pin 22.

3.2.1.2.2.2 Extended Limit Operate Mode: Apply +6 vdc to pin 22. The input levels of the preceding diagram shall be increased by the factor 8.9 to produce the same input pattern of output voltages and switching times.

3.2.1.2.2.3 Standby Mode: This mode is described in Paragraph 3.2.2.

3.2.2 Sensor Torquers

The following requirements pertain to the pitch (SK92532), roll (SK92531), and yaw (SK92533) axis sensor torquers.



$T_3 - T_2 = 17 \pm 1.7 \times 10^{-3}$ SECONDS

& $T_5 - T_4 = 17 \pm 1.7 \times 10^{-3}$ SECONDS

& $T_7 - T_6 = 5 \pm 1 \times 10^{-3}$ SECONDS

& $T_9 - T_8 = 37.7 \pm 4 \times 10^{-3}$ SECONDS

Figure III-1. Input-Output Relationships for Axis Computers

3.2.2.1 Input Characteristics

3.2.2.1.1 Power --

3.2.2.1.1.1 Pin 11. +20 ± 1 vdc at 100 ma maximum from a maximum source impedance of 3 ohms containing less than 0.3 v rms each of 400 and 800 cps.

3.2.2.1.1.2 Pin 9: -20 ± 1 vdc at 100 ma maximum from a max source impedance of 3 ohms containing less than 0.3 v rms each of 400 and 800 cps.

3.2.2.1.1.3 Pin 23: +6 ± 0.25 vdc at 2.5 ma maximum from 3 ohms maximum source impedance containing less than 0.1 v rms each of 400 and 800 cps.

3.2.2.1.1.4 Pin 3: +12 ± 0.5 vdc at 0.5 ma from a maximum source impedance of 3 ohms containing less than 0.2 v rms each of 400 and 800 cps.

3.2.2.1.1.5 Pin 1: -12 ± 0.5 vdc at 3.5 ma from a maximum source impedance of 3 ohms containing less than 0.2 v rms each of 400 and 800 cps.

3.2.2.1.2 Signal --

3.2.2.1.2.1 Standby Mode (gyro synchronization): 0 ± 0.1 vdc at pin 4

3.2.2.1.2.2 Operate Mode: +6 ± 0.1 vdc at pin 4

3.2.2.1.2.3 Rotational Rate Commands

Output	Input (vdc) and Pin No.					
Attitude Rate (deg/sec)	7	8	17	6	5	18
0	0	0	0	0	0	0
+20	+6	0	0	0	0	0
-20	0	0	0	+6	0	0
+ 3	0	+6	0	0	0	0
- 3	0	0	0	0	+6	0
+ 0.15	0	0	+6	0	0	0
- 0.15	0	0	0	0	0	+6

3.2.2.1.3 Noise -- Noise levels are not to exceed 0.1 v rms each at 400 and and 800 cps.

3.2.2.2 Output Characteristics

With a 170-ohm load connected between pins 12 and 16 of 3K32531 the input-output characteristics shall be as follows:

Input (vdc) and Pin No.						Output*
7	8	17	6	5	18	Load Current (ma), Pins 12 to 16
+6	0	0	0	0	0	+90
0	+6	0	0	0	0	+13.5
0	0	+6	0	0	0	+ 0.676
0	0	0	+6	0	0	-90
0	0	0	0	+6	0	-13.5
0	0	0	0	0	+6	- 0.676
0	0	0	0	0	0	0

*Signs refer to the polarity of pin 12.
Current tolerance is ±10 percent

3.3 Reaction Jet Drivers (SK92530)

3.3.1 Input Characteristics

3.3.1.1 Power --

3.3.1.1.1 +28 ± 4 vdc at 360 ma maximum from a source impedance of less than 3 ohms.

3.3.1.1.2 +12 ± 0.5 vdc at 6.4 ma maximum from a source impedance of less than 3 ohms containing less than 0.2 v rms each of 400 and 800 cps.

3.3.1.1.3 -12 ± 0.5 vdc at 0.64 ma maximum from a source impedance of less than 3 ohms containing less than 0.2 v rms each of 400 and 800 cps.

3.3.1.2 Signal -- The input signal for each input point shall be either 0 ± 0.5 vdc or +6 ± 0.5 vdc from a source impedance of less than 3 ohms containing less than 0.1 v rms each of 400 and 800 cps.

3.3.2 Output Characteristics

The output points shall be loaded with 2.6 ohms to ground. With all input points at 0 ± 0.5 vdc, all output points shall be 0 ± 0.01 vdc. When any input is raised to +6 ± 0.5 vdc the corresponding output shall become +0.11 vdc ± 0.01 v. Input points are denoted on SK92530 by the letters A through H, and corresponding output points are denoted by the same letters followed by the subscript D.

3.4 Power Supply

3.4.1 Input Characteristics

Input shall be +28 ± 4 vdc at 2 amperes maximum from a source impedance of less than 0.1 ohms. Voltage source excursions below 24 vdc shall be limited to 15×10^{-6} seconds. Voltage excursions above 32 vdc shall be limited to 40 vdc maximum amplitude and 0.1 second maximum duration at a maximum pulse recurrent frequency of 0.1 cps.

3.4.2 Output Characteristics

The circuit of SK92534 must be properly connected to the reference transformer and the power transformer per SK92539 in order to evaluate its operation. When properly connected, and with primary power of 3.4.1 applied to pin 7, the power supply shall have the following output capabilities:

3.4.2.1 Pin 6: +6 ± 0.5 vdc at 150 ma maximum with a source impedance of 3 ohms maximum containing less than 0.1 v rms each of 400 and 800 cps.

3.4.2.2 Pin 20: +12 ± 0.2 vdc at 30 ma maximum with a source impedance of 3 ohms maximum containing less than 0.2 v rms each of 400 and 800 cps.

3.4.2.3 Pin 17: -12 ± 0.4 vdc at 100 ma maximum with a maximum source impedance of 3 ohms containing less than 0.2 v rms each of 400 and 800 cps.

3.4.2.4 Pin 24: +20 ± 1 vdc at 300 ma maximum from a maximum source impedance of 3 ohms and containing less than 0.3 v rms each of 400 and 800 cps.

3.4.2.5 Pin 22: -20 ± 1 vdc at 300 ma maximum from a maximum source impedance of 3 ohms and containing less than 0.3 v rms each of 400 and 800 cps.

3.4.2.6 +6 ± 0.1 v rms at 1.2 va both in and out of phase of a 400 cps ±5 percent square wave having a maximum rise and fall time of 100 microseconds.

3.4.2.7 +28 ± 0.5 v rms at 12 va of a 400 cps ±5 percent square wave having a maximum rise and fall time of 100 microseconds

4.0 DETAIL ACS ELECTRONICS PACKAGE REQUIREMENTS

All pin numbers in the following discussion refer to those shown on SK92539.

4.1 Load Simulation

4.1.1 Jet Solenoid -- Connect 28-ohm, 50-watt resistors between J1 pins 41, 42, 43, 44, 45, 46, 47, and 48 and the +28 vdc supply.

4.1.2 Gyro Torquer -- Connect 170-ohm, 2-watt resistors between J2 pins 17 and 18, 26 and 27, and 33 and 34.

4.1.3 Temperature Sensor -- Connect a 1000-ohm potentiometer between J2 pins 29 and 30.

4.1.4 Sensor Heater -- Connect a 2.6-ohm, 5-watt resistor between J2 pins 8 and 9.

4.1.5 Sensor Signal Generator -- Connect a 40-ohm, 1-watt resistor between J2 pins 14 and 15.

4.1.6 Sensor Spinmotor -- Connect an 87-ohm, 10-watt resistor in series with a 21-millihenry choke between J2 pins 11 and 12.

4.2 Signal Source Simulation

Connect 1 kilohm, 0.5-watt resistors between J2 pins 4 and 5, 23 and 24, and 36 and 37; and connect J2 pins 5, 24, and 37 to J1 pin 2.

4.3 Standby Mode Operation

4.3.1 Apply +28 vdc to J1 pin 1 and 28 v ground to J1 pin 2. Then:

+28 vdc shall appear at J3 pin 1

28 ± 2 v rms 400 ± 10 cps shall appear at J3 pin 4

6 v rms ±10 percent 400 ± 10 cps shall appear at J3 pins 6 and 7 (The waveform at pin 7 shall be out of phase with that at pin 6.)

+6 ± 0.5 vdc shall appear at J3 pin 9

+12 ± 0.2 vdc shall appear at J3 pin 11

-12 ± 0.4 vdc shall appear at J3 pin 12

+20 ± 1 vdc shall appear at J3 pin 14

-20 ± 1 vdc shall appear at J3 pin 15

4.3.2 Pitch Sensor Torque -- Connect J3 pin 6 through 682 kilohms to J2 pin 4. Voltage between J2 pins 17 and 18 shall be 1.7 ± 0.17 vdc, with pin 18 positive. Disconnect the 682-kilohm resistor from J3 pin 6 and reconnect to J3 pin 7. Voltage between J2 pins 17 and 18 shall be 1.7 ± 0.17 vdc, with pin 18 negative.

4.3.3 Roll Sensor Torque -- Connect J3 pin 6 through 682 kilohms to J2 pin 23. Voltage between J2 pins 26 and 27 shall be 1.7 ± 0.17 vdc, with pin 27 positive. Disconnect the 682-kilohm resistor from J3 pin 6 and reconnect to J3 pin 7. Voltage between J2 pins 26 and 27 shall be 1.7 ± 0.17 vdc, with pin 27 negative.

4.3.4 Yaw Sensor Torque -- Connect J3 pin 6 through 682 kilohms to J2 pin 36. Voltage between J2 pins 33 and 34 shall be 1.7 ± 0.17 vdc, with pin 34 positive. Disconnect the 682-kilohm resistor from J3 pin 6 and reconnect to J3 pin 7. Voltage between J2 pins 33 and 34 shall be 1.7 ± 0.17 vdc, with pin 34 negative.

4.3.5 Connect J1 pins 4, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, and 22 to J2 pin 2 and connect J1 pin 24 to J3-9. Voltages between J2-17 and 18, J2-26 and 27, and J2-33 and 34 shall fall below 0.3 v in absolute magnitude.

4.4 Normal Limit Operate Mode

4.4.1 Command Torque:

4.4.1.1 +20 deg/sec -- Remove the connections to J2 pins 4,23, and 36. Remove the connections from J1 pins 4, 11, and 17 and connect these pins to J3 pin 9. The voltages between J2 pins 17 and 18, 26 and 27, and 33 and 34 shall become 14.85 ± 0.75 vdc with pins 18, 27, and 34 positive.

4.4.1.2 -20 deg/sec -- Remove the connection to J1 pins 4, 11, and 17 and connect these pins to J1-2. Remove the connections previously made from J1 pins 7,14, and 20, and connect these pins to J3-9. The voltage between J2 pins 17 and 18, 26 and 27, and 33 and 34 shall become 14.85 ± 0.75 vdc, with pins 18 27, and 34 negative.

4.4.1.3 +3 deg/sec -- Remove the connections previously made on J1 pins 7, 14, and 20, and connect these pins to J3-10. Remove the connections to J1 pins 5,12, and 18, and connect these pins to J3-9. The voltage between J2 pins 17 and 18, 26 and 27, and 33 and 34 shall become 2.22 ± 0.11 vdc, with J2 pins 18, 27, and 34 positive.

4.4.1.4 -3 deg/sec -- Remove the connections previously made to pins J1-5, 12, and 18, and connect these pins to J3-10. Remove the connections to J1 pins 8, 15, and 21, and connect these pins to J3-9. The voltage between J2 pins 17 and 18, 26 and 27, and 33 and 34 shall become 2.22 ± 0.11 vdc, with J2 pins 18, 27, and 34 negative.

4.4.1.5 +0.15 deg/sec -- Remove the connections previously made to J1 pins 8, 15, and 21, and connect these pins to J3-10. Remove the connections previously made to J1 pins 6, 13, and 19, and connect these pins to J3-9. The voltage between J2 pins 17 and 18, 26 and 27, and 33 and 34 shall become 0.111 ± 0.011 vdc, with J2 pins 18, 27, and 34 positive

4.4.1.6 -0.15 deg/sec -- Remove the connections previously made to J1 pins 6, 13, and 19, and connect these pins to J3-10. Remove the connections previously made to J1-pins 9, 16, and 22, and connect these pins to J3-9. The voltage between J2 pins 17 and 18, 26 and 27, and 33 and 34 shall become 0.111 ± 0.011 vdc, with J2 pins 18, 27, and 34 negative.

4.4.2 Translation Command:

Voltage output at J1 pins 41 through 48 shall be 28 vdc from the primary 28 vdc source when J1 pins 4 through 9, 11 through 16, 17 through 22, and 34 through 39 are connected to J3-10.

4.4.2.1 +X, Forward Translation -- Remove the previously made connection from J1-34 and connect J1-34 to J3-9. J1 pins 42, 43, 46, and 47 shall become +1 ± 0.5 vdc. Remove the connection from J1-34 to J3-9 and make the connection J1-34 to J3-10. J1 pins 42, 43, 46, and 47 shall be +28 ± 4 vdc.

4.4.2.2 -X, Aft Translation -- Remove the previously made connection from J1-35 and connect J1-35 to J3-9. J1 pins 41, 44, 45, and 48 shall become +1 ± 0.5 vdc. Remove the connection J1-35 to J3-9 and connect J1-35 to J3-10. J1 pins 41, 44, 45, and 48 shall become +28 ± 4 vdc.

4.4.2.3 +Y, Right Translation -- Remove the previously made connection to J1-36 and connect J1-36 to J3-9. J1 pins 43, 44, 47, and 48 shall become +1 ± 0.5 vdc. Remove the connection J1-36 to J3-9 and make the connection J1-36 to J3-10. J1 pins 43, 44, 47, and 48 shall become +28 ± 4 vdc.

4.4.2.4 -Y, Left Translation -- Remove the previously made connection from J1-37 and make the connection J1-37 to J3-9. J1 pins 41, 42, 45, and 46 shall become +1 ± 0.5 vdc. Remove the connection J1-37 to J3-9 and make the connection J1-37 to J3-10. J1 pins 41, 42, 45, and 46 shall become +28 ± 4 vdc.

4.4.2.5 +Z, Down Translation -- Remove the previously made connection from J1-38 and make the connection J1-38 to J3-9. J1 pins 41, 42, 43, and 44 shall become +1 ± 0.5 vdc. Remove the connection J1-38 to J3-9 and make the connection J1-38 to J3-10. J1 pins 41, 42, 43, and 44 shall become +28 ± 4 vdc.

4.4.2.6 -Z, Up Translation -- Remove the previously made connection from J1-39 and make the connection J1-39 to J3-9. J1 pins 45, 46, 47, and 48 shall become +1 ± 0.5 vdc. Remove the connection J1-39 to J3-9 and make the connection J1-39 to J3-10. J1 pins 45, 46, 47, and 48 shall become +28 ± 4 vdc.

4.4.3 Attitude Stabilization:

The entries in the body of Table III-1 indicate the outputs that shall occur when the system is stimulated by the inputs shown in the input column.

4.4.4 Temperature Control:

Connect the wiper of the potentiometer connected between J2 pins 29 and 30 to J2-30. Adjust the wiper position until the resistance applied between J2 pins 29 and 30 is 770 ohms. A minimum of 18 milliamperes shall flow through the 2.6-ohm resistor connected between J2 pins 8 and 9. Adjust the wiper position until the resistance applied betwen J2 pins 29 and 30 is 790 ohms. A maximum of 10 microamperes shall flow through the 2.6-ohm resistor connected between J2 pins 8 and 9.

Table III-1. Attitude Stabilization Input-Output Relationships

Input*		Output* - Pin J1							
Pin J2	Level and Phase** (v rms)	41	42	43	44	45	46	47	48
4*	∿0.201	28†	1-17†	1-17	28	1-17	28	28	1-17
23	∿0.201	1-17	1-17	28	28	28	28	1-17	1-17
36	∿0.201	28	1-17	28	1-17	28	1-17	28	1-17
4	✓0.201	1-17	28	28	1-17	28	1-17	1-17	28
23	✓0.201	28	28	1-17	1-17	1-17	1-17	28	28
36	✓0.201	1-17	28	1-17	28	1-17	28	1-17	28
4	∿0.25	28	1-37†	1-37	28	1-37	28	28	1-37
23	∿0.25	1-37	1-37	28	28	28	28	1-37	1-37
36	∿0.25	28	1-37	28	1-37	28	1-37	28	1-37
4	✓0.25	1-37	28	28	1-37	28	1-37	1-37	28
23	✓0.25	28	28	1-37	1-37	1-37	1-37	28	28
36	✓0.25	1-37	28	1-37	28	1-37	28	1-37	28
4	∿0.175	28	28	28	28	28	28	28	28
23	∿0.175	28	28	28	28	28	28	28	28
36	∿0.175	28	28	28	28	28	28	28	28
4	✓0.175	28	28	28	28	28	28	28	28
23	✓0.175	28	28	28	28	28	28	28	28
36	✓0.175	28	28	28	28	28	28	28	28

*Input pins are connected to the axis computer inputs. Output pins have simulated solenoid loads connected per Paragraph 4.1.1.

** ∿0.201 v rms is 0.201 v rms 400 cps square wave in phase with J3-6.

✓0.25 v rms is 0.25 v rms 400 cps square wave out of phase with J3-6.

†1-17 is +1 ± 0.5 vdc output level for 17 ± 1.7 milliseconds.

1-37 is +1 ± 0.5 vdc output level for 37.7 ± 4 milliseconds.

28 is +28 ± 4 vdc output continuous.

4.5 Extended Limit Operate Mode

Connect J1-25 to J3-9.

4.5.1 Command Torque -- Per 4.4.1.

4.5.2 Translation Command -- Per 4.4.2.

4.5.3 Attitude Stabilization -- Per 4.4.3, except that the 0.201 v rms input signal becomes 1.785 v rms, the 0.25 v rms input signal becomes 2.22 v rms, and the 0.175 v rms input signal becomes 1.555 v rms.

SECTION IV

SPECIFICATION FOR THE ASTRONAUT MANEUVERING UNIT VOICE CONTROLLER BREADBOARD

SECTION IV
SPECIFICATION FOR THE ASTRONAUT MANEUVERING UNIT VOICE CONTROLLER BREADBOARD

1.0 SCOPE

This specification contains a technical description of a voice controller to be used by an astronaut in addressing translational or rotational commands to an attitude control system (ACS).

2.0 APPLICABLE DOCUMENTS

a. NASA Contract NASw-841

b. Section I, "Requirements for the Astronaut Maneuvering Unit Attitude Control System," of this volume (Volume II) of 1781-FR1, 15 June 1964

3.0 REQUIREMENTS

3.1 General Design Requirements

The ACS controller shall be designed to operate from certain specified voice outputs of the astronaut. Unnatural variations of those outputs in volume or pitch shall not have a detrimental effect on controller operation. The controller shall not interfere with normal voice communication, with the environmental support system, or with the visual and mobility functions of the astronaut.

3.1.1 Three functions shall be included: voice input, speech recognition, and control signal generation.

3.1.2 A microphone system shall be used, whether of the close-talking or contact type, that has the sensitivity, fidelity, frequency response, and dynamic range characteristics necessary to transduce the speech commands specified in Paragraph 3.2.1 reliably and without distortion.

3.2 Functional Characteristics

3.2.1 The controller shall respond to the following words, uttered as vocal inputs:

Roll	X	Plus	Stop
Pitch	Y	Minus	Cage
Yaw	Z		

The controller shall not respond to any other vocal inputs.

3.2.2 Rotational Control

3.2.2.1 The astronaut shall select a rotation maneuver by uttering one of the following three terms: roll, pitch, yaw. These terms shall correspond to body rotations about the x, y and z axes, respectively. Any rotation command can be changed to any other maneuver command prior to its execution.

3.2.2.2 Speed selection shall be performed by uttering the maneuver word in a repetitive manner, as follows:

Maneuver Word	Rotation Rate
Uttered once	Precision
Uttered twice	Low
Uttered three times	High

3.2.2.3 A direction for the maneuver shall be selected by uttering the word "plus" or "minus". Such utterance shall normally occur immediately following the maneuver and speed command utterances.

3.2.2.4 The direction command shall also constitute the execution command for the ACS, such that its utterance will cause the ACS to perform the desired rotation maneuver at the speed and direction commanded.

3.2.2.5 The duration of the rotation maneuver shall be governed by repetitions of the execution (direction) command. The maneuver shall be sustained as long as the appropriate command is repeated. The rate of repetition required to sustain a maneuver shall not be greater than one word per second.

3.2.3 Translational Control

3.2.3.1 The astronaut shall select a translation maneuver by uttering one of the following three terms: X, Y, Z. The terms shall correspond to body translations along the x, y, and z axes, respectively. Any translation command can be changed to any other maneuver command prior to its execution.

3.2.3.2 Acceleration selection shall be performed by uttering the maneuver word in a repetitive manner, as follows:

Maneuver Word	Translation Acceleration
Uttered once	Low
Uttered twice	High

3.2.3.3 A direction for the maneuver shall be selected by uttering the word "plus" or "minus". Such utterance shall normally occur immediately following the maneuver and acceleration command utterances.

3.2.3.4 The direction command shall also constitute the execution command for the ACS, such that this utterance will cause the ACS to perform the desired translation maneuver at the acceleration and direction commanded.

3.2.3.5 The duration of the translation maneuver shall be governed by repetitions of the execution (direction) command. The maneuver shall be sustained as long as the appropriate command is repeated. The rate of repetition required to sustain a maneuver shall not be greater than one word per second.

3.2.4 Stop Control

3.2.4.1 The single word "stop", uttered at any time, shall immediately remove all verbal commands from the ACS system. The translational system shall revert to Coast mode, and the ACS shall revert to attitude hold using as a reference the attitude that existed at the time the "stop" command was given.

3.2.4.2 No release or engage function by the operator shall be necessary for the system to accept new commands after the "stop" command has been given. Normal operation should resume when a normal verbal command sequence is given.

3.2.5 Gyro Caging Control

3.2.5.1 The phrase "stop-cage", uttered at any time, shall immediately remove all verbal commands from the ACS and place the gyros in an attitude synchronous mode of operation. Reaction jet operation shall be prevented.

3.2.5.2 No release or engage function by the operator shall be necessary for the system to accept new commands after the cage command has been given. Normal operation should resume when a normal verbal command sequence is given. Attitude reference shall be that existing at the time the cage command was given, provided angular rates were less than 20 deg/sec.

3.2.6 Deadband Control

3.2.6.1 The phrase "stop-plus", uttered at any time during normal operation, shall immediately provide the ACS with wide (±10 degrees) deadband limits in all body axes. The ACS shall retain the wide limits until the astronaut selects the narrow deadband limits as specified in Paragraph 3.2.6.2 or until a precision rate of rotation is commanded.

3.2.6.2 The phrase "stop-minus", uttered at any time during normal operation, shall immediately provide the ACS with narrow (±0.8 degree) deadband limits in all body axes. The ACS shall retain the narrow limits until the astronaut selects the wide deadband limits as specified in Paragraph 3.2.6.1. The narrow limits shall be removed and the system shall revert to the wide limits any time the ACS is placed in the caged mode.

3.3 Performance Characteristics

3.3.1 The dynamic range of the speech controller shall be 30 db. It shall provide normal signal inputs to the ACS when the operator's voice intensity varies over a range corresponding to sound pressure levels from 59 to 89 db one meter from the speaker.

3.3.2 The response time of the voice input and speech recognition functions shall be such that appropriate electrical outputs shall result from the 10 permissible vocal inputs in 0.1 second or less, measured peak-to-peak (speech peak-to-signal peak).

3.4 Electrical Characteristics

3.4.1 The thrust logic outputs of the controller to the ACS sensors and electronics shall be designated:

O - Positive x-axis acceleration
P - Negative x-axis acceleration

Q - Positive y-axis acceleration
R - Negative y-axis acceleration
S - Positive z-axis acceleration
T - Negative z-axis acceleration

3.4.2 Logic Designation

The controller shall switch a given logic output from 0 to 1 by changing the characteristics of the voltage applied to a wire according to the following:

State	Voltage (vdc)	Source Impedance (K ohm max)
0	0 ± 0.5	4.5
1	+6 ± 0.5	4.5

3.4.3 There shall be 20 torquing commands to the electronics consisting of voltages with the characeristics given in Paragraph 3.4.2:

ACS OFF	Pitch Hi Neg
Yaw Hi Pos	Pitch Lo Neg
Yaw Lo Pos	Pitch Precision Neg
Yaw Precision Pos	Roll Hi Pos
Yaw Hi Neg	Roll Lo Pos
Yaw Lo Neg	Roll Precision Pos
Yaw Precision Neg	Roll Hi Neg
Pitch Hi Pos	Roll Lo Neg
Pitch Lo Pos	Roll Precision Neg
Pitch Precision Pos	Deadband Set

3.5 Physical Characteristics

3.5.1 The voice controller breadboard, which shall be taken to include the voice input section, the speech analyzer section, and the signal output section, shall not exceed 1.5 cubic feet in volume.

3.5.2 The voice controller, as defined in Paragraph 3.5.1, shall not weigh more than 20 pounds.

3.5.3 A design goal shall be to use parts suitable for use in a space qualified device.

4.0 BREADBOARD TESTS

4.1 Selected environmental tests shall be performed to assure that the design is suitable for use in a space environment.

4.2 Tests performed shall be consistent with the degree to which components suitable for space use are used in the breadboard equipment.